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Proton and Neutron Halos of β-Emitting Nuclei Detected by Nuclear Quadrupole Moments

THE OSAKA UNIVERSITY TOYONAKA, OSAKA

GRADUATE SCHOOL OF SCIENCE

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DISSERTATION IN PHYSICS



Proton and Neutron Halos of β-Emitting Nuclei Detected by Nuclear Quadrupole Moments

Takashi Ohtsubo

ABSTRACT

 $= 2^+, T_{1/2} = 0.84$ s), ${}^8B(I^{\pi} = 2^+, T_{1/2} = 0.769$ s), ${}^{12}B(I^{\pi} = 1^+, T_{1/2} = 0.769$ s) For the present purpose, the electric quadrupole interactions of each NMR of ¹²B in a crystal.

In order to observe very small electric quadrupole effects in the β -NMR spectra of β emitters, the conventional β -NMR was very much improved as a New Nuclear Quadrupole Resonance Technique (NNQR). This technique is especially efficient and was designed to study the quadrupole interactions of high-spin states.

The quadrupole coupling constants were determined to be $leqQ/h(^{8}Li$ in $LiIO_3| = 29.6 \pm 1.1 \text{ kHz}, |eqQ/h(^8Li \text{ in } LiNbO_3)| = 44.68 \pm 0.88 \text{ kHz},$ $|eqQ/h(^{8}B \text{ in Mg})| = 243.6 \pm 6.0 \text{ kHz}, |eqQ/h(^{12}B \text{ in BN})| = 944 \pm 17 \text{ kHz},$ $|eqQ/h(^{12}B \text{ in } Mg)| = 47.0 \pm 0.1 \text{ kHz}, |eqQ/h(^{12}N \text{ in } BN)| = 56.8 \pm 3.2 \text{ kHz}$

The nuclear quadrupole moments of light short-lived nuclei in a region far from stability lines have been determined in order to study their nuclear structures and to identify the neutron and proton halos in nuclei. For this purpose, the nuclear quadrupole moments of short-lived β emitters (⁸Li($I\pi$) 20.2 msec), and ${}^{12}N(I^{\pi} = 1^+, T_{1/2} = 11.0 \text{ msec}))$ were precisely measured. nucleus implanted in several selected single crystals were studied by detecting the β -NMR of the β emitters. The crystals in which well-defined electric field gradients were obtained were LiIO₃, LiNbO₃, highly oriented BN, and GaN. In these crystals the implanted β emitters were located at substitutional sites of their stable isotopes. ⁸B and ¹²B nuclei were also implanted in a Mg crystal in order to utilize any internal field gradients obtained at its interstitial site. The field gradients in insulator crystals were measured by detecting the Fourier-Transformed NMR (FT-NMR) of stable isotopes of ⁷Li, ¹¹B and ¹⁴N in LiIO₃, LiNbO₃, BN and GaN, respectively. Also, the field gradient in a Mg crystal was measured by detecting the β - and $|eqQ/h(^{12}N \text{ in } \text{GaN})| = 27.5 \pm 2.0 \text{ kHz}$. For stable isotopes, the coupling constants were determined to be $|eqQ/h(^{7}\text{Li} \text{ in } \text{LiIO}_3)| =$ $36.4 \pm 0.5 \text{ kHz}$, $|eqQ/h(^{7}\text{Li} \text{ in } \text{LiNbO}_3)| = 53.3 \pm 0.5 \text{ kHz}$, $|eqQ/h(^{11}\text{B} \text{ in}$ BN)| = 2902 ± 12 kHz, $|eqQ/h(^{14}N \text{ in } \text{BN})| = 110.7 \pm 4.1 \text{ kHz}$ and $|eqQ/h(^{14}N \text{ in } \text{GaN})| = 49 \pm 15 \text{ kHz}$. Since the quadrupole moments of the stable isotopes are known to be $Q(^{7}\text{Li}) = +40.0 \pm 0.6 \text{ mb } Q(^{11}\text{B}) =$ $+40.59 \pm 0.10 \text{ mb } [\text{Su91}] \text{ and } Q(^{14}\text{N}) = +20.0 \pm 0.2 \text{ mb } [\text{Sc92}]$, the electric field gradients were obtained to be $|q(\text{Li} \text{ site of } \text{LiIO}_3)| = 3.8 \pm 0.1 \times 10^{19}$ V/m^2 , $|q(\text{Li} \text{ site of } \text{LiNbO}_3)| = 5.5 \pm 0.1 \times 10^{19} \text{ V/m}^2$, |q(B site of BN)| = $2.96 \pm 0.02 \times 10^{21} \text{ V/m}^2$, $|q(\text{N} \text{ site of } \text{BN})| = 2.29 \pm 0.24 \times 10^{20} \text{ V/m}^2$ and . $|q(\text{N} \text{ site of } \text{GaN})| = 1.0 \pm 0.3 \times 10^{20} \text{ V/m}^2$. Finally, the quadrupole moments of β -emitting nuclei were determined to be $|Q(^8\text{Li})| = 32.7 \pm 0.6$ mb, $|Q(^8\text{B})| = 68.3 \pm 2.1 \text{ mb}$, $|Q(^{12}\text{B})| = 13.20 \pm 0.25 \text{ mb and } |Q(^{12}\text{N})| =$ $10.3 \pm 0.7\text{mb}$.

The value of $Q(^{8}B)$ is twice as large as that predicted by the Cohen-Kurath wave functions in the harmonic-oscillator potential. It was found by subtracting the contribution of deeply bound neutrons that the last valence proton in ^{8}B carry more than 90% of the observed moment. This value is accounted for by the Cohen-Kurath wave functions in a Woods Saxon potential in which the depth of the potential was adjusted so as to reproduce the empirical nucleon separation energies. This anomalous value is accounted for by the proton halo due to the loosely bound valence configuration. This is the first experimental evidence of a proton halo covering a neutron core. Similarly, the neutron contribution in $Q(^{8}Li)$ suggests a neutron skin covering a proton core.

The value of $Q(^{12}B)$ is in good agreement with that predicted by the Cohen-Kurath wave functions in the Woods Saxon potential. A thin, but definite, neutron skin is clearly shown, which results from a rather shallowly bound neutron configuration.

In spite of the rather shallow configuration of the valence proton in ¹²N (the one proton separation energy is 0.6 MeV), the experimental value, $|Q(^{12}N)|$, is well reproduced by the Cohen Kurath wave functions in the harmonic-oscillator potential, $Q(^{12}N, HO) = 11$ mb, rather than in the Woods Saxon potential, $Q(^{12}N, WS) = 5$ mb. Additional theoretical studies concerning its structure are needed.

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Chapter 1

INTRODUCTION

The electric quadrupole moment of a nucleus is one of the best probes for studying the nuclear structure and nucleon-nucleon interactions. It gives the deviation of the electric charge distribution, i.e., the angular and radial nucleon distributions, in a nucleus from its spherically symmetric distribution [Mi92, Ki93]. It therefore directly gives the angular and radial distributions of valence nucleons in the nucleus, especially when its core is spherical.

Among others, the electromagnetic moments of nuclei in a 1p shell (4 <Z, N < 16) have been well studied both experimentally and theoretically. The nuclear properties, level energies, nuclear magnetic moments and nuclear quadrupole moments have been well reproduced by systematic shell model studies. The first such inclusive study concerning this 1p shell was carried out by Cohen and Kurath (CK) in 1965 [Co65]. In their framework they derived the effective nuclear interaction working in the 1p shell by fitting the known energy levels. Their success was because of only small configuration mixing effects in the wave functions of 1p-orbitals with those of 1d-orbitals. This suppression is due to the rather large energy difference between the 1p-orbitals and upper 1d-orbitals. Following their successes, the technique has been improved and expanded by many nuclear physicists to meet the present dramatically increasing precise nuclear data. Regarding the nuclear quadrupole moments of the nuclear ground states, the known values that are experimentally unambiguous are well reproduced by the CK wave functions in the harmonic-oscillator potential. For example, the quadrupole moments of ¹¹B, and ¹¹C are well reproduced theoretically by Sagawa and Kitagawa [Sa93]. Unfortunately,

although the quadrupole moments of ⁸Li and ¹²N are known, the values are not decisive, because of various experimental difficulties. It has also been understood that the values of ⁸B and ¹²N, even though we need them for the present aim of the study, may not be measured without developing some ingenious experimental techniques.

Owing to the recent experimental progress in producing unstable nuclear beams, new studies concerning unstable nuclei far from the stable line have become possible, and completely new nuclear phenomena have been disclosed. Among such studies, measurements of interaction cross sections of unstable nuclei at a high energy of 800A MeV with stable nuclei was started by Sugimoto and Tanihata at Lawrence Berkeley Laboratory [Ta85]. Based on this systematic study, a peculiar phenomenon, a huge neutron halo in the neutron-rich nucleus ¹¹Li, was discovered. An increase in the root mean square radius (rms radius) $\delta \langle r^2 \rangle^{\frac{1}{2}} (^{11}\text{Li}) = \langle r^2 \rangle^{\frac{1}{2}} (^{11}\text{Li}) - \langle r^2 \rangle^{\frac{1}{2}} (^{11}\text{Li})$ reached as large as ~0.8 fm. Here, $\langle r^2 \rangle^{\prime \prime}$ (¹¹Li) is the rms radius of ¹¹Li estimated from the known rms radii of the lighter Li isotopes [Ta85]. Several theoretical calculations with a Hartree-Fock model have been reported [Ta89], but they fail to reproduce the experimentally determined radii of neutron rich nuclei. Bertch et al. [Be89] pointed out the importance of the separation energies of valence nucleons; the density distribution of very shallowly bound nucleons in the nucleus is greatly extended outside the core formed by the rest nucleons. Their calculation was able to reproduce the interaction radii quite well in neutron rich nuclei.

Such halos, however, have been discovered only in neutron-rich nuclei, and not in proton-rich nuclei, by the interaction cross section measurements. Theoretically, it is understood that a prominent proton halo in proton rich nucleus is difficult to be formed since such a similar halo effect for protons is suppressed by the existence of repulsive Coulomb

force and/or centrifugal force in the nucleus [Ta89]. But, because of the charge symmetry of the nuclear force, a proton skin, no matter how thin it is, can be expected especially in the light proton rich nuclides. Therefore, not depending on whether a radial matter swelling exists or not, a very thin halo or skin must be experimentally confirmed.

To detect any effects, such a thin skin, by measuring the interaction cross sections is not very clever way, since it is mainly designed to detect total matter distributions, but not such thin-skin effects. In this cross section, the effects due to the skin is only a small fluctuation in the total cross section. On the other hand, an ingenious technique to measure the nuclear quadrupole moment of a proton-rich nucleus is especially suitable and sensitive for and to the skin effect, since the value is solely dependent on the radial and angular distributions of the last valence nucleons at the nuclear surface for a spherical nucleus.

to have conclusive values.

Regarding the experimental technique to measure the quadrupole moments, because all those interesting nuclides are β -emitting and short-

Of specific interest is the mirror pairs of mass A = 8 and 12 systems: ⁸Li, ⁸B, ¹²B and ¹²N. The ⁸B nucleus, whose quadrupole moment has not yet been studied, is one of the best candidates for a proton halo or skin, since the separation energy of the last proton is only 137keV, which is an extremely small value compared with a normal one which has ~8MeV for stable nuclei. The one-nucleon separation energies of the rest nuclides are also relatively small, as shown in Table 1-1. Regarding the nuclear quadrupole moments of the four nuclides, only the experimental value of $^{12}B, Q(^{12}B)$, is reliably known [Mi78]. Since huge discrepancies are known among the reported values for each ${}^{12}N$ or ${}^{8}Li$ nuclides, $Q({}^{12}N)$ [Ra80, Mi70] and Q(⁸Li) [Ac74, Mi75], the values of which are not precise enough for the present aim of studies must be experimentally remeasured

Table 1-1 Separation energy of the last nucleon in p-shell nuclei. $E_{sp}(N)$ is the one nucleon separation energy. Nuclei given by Bold characters nuclei are studied in the present experiment. Nuclei given by Italic characters nuclei are candidates that may have halos. Nuclei given by Bold italic characters are observed halo or skin structure that may have [Br86].

| Nucleus | Z | N | Ιπ | $E_{sp}(p)$ (MeV) | $E_{sp}(n)$ (MeV) |
|------------------|---|----|--------|-------------------|-------------------|
| 6 _{He} | 2 | 4 | 0+ | - | 1.450 (2n) |
| 6 _{Li} | 3 | 3 | 1+ | - | - |
| 7 _{Li} | 3 | 4 | 3/2- | 9.975 | 7.251 |
| ⁷ Be | 4 | 3 | 3/2- | 5.607 | - |
| 8 _{He} | 2 | 6 | 0+ | _ | 2.136 (2n) |
| 8 _{Li} | 3 | 5 | 2+ | 12.454 | 2.032 |
| 8 _B | 5 | 3 | 2+ | 0.137 | 13.021 |
| 9 _{Li} | 3 | 6 | 3/2- | 13.933 | 4.062 |
| 9 _{Be} | 4 | 5 | 3/2- | 16.886 | - |
| ⁹ C | 6 | 3 | (3/2-) | 1.296 | - |
| 10 _{Be} | 4 | 6 | 0+ | 19.636 | 6.812 |
| 10 _B | 5 | 5 | 3+ | 6.587 | - |
| 10C | 6 | 4 | 0+ | - | 21.283 |
| 11 _{Li} | 3 | 8 | 3/2(-) | | 0.197 (2n) |
| 11Be | 4 | 7 | 1/2+ | - | 0.504 |
| 11 _B | 5 | 6 | 3/2- | 11.228 | 11.453 |
| 11C | 6 | 5 | 3/2- | 8.689 | 13.122 |
| 12 _{Be} | 4 | 8 | 0+ | 23.112 | 3.168 |
| 12 _B | 5 | 7 | 1+ | 14.094 | 3.370 |
| ² C | 6 | 6 | 0+ | 15.957 | 18.721 |
| ² N | 7 | 5 | 1+ | 0.601 | - |
| 3 _B | 5 | 8 | 3/2- | - | 4.878 |
| ¹³ C | 6 | 7 | 1/2- | 17.533 | 4.946 |
| ³ N | 7 | 6 | 1/2- | 1.943 | 20.063 |
| 30 | 8 | 5 | (3/2-) | 1.516 | - |
| ⁴ Be | 4 | 10 | 0+ | - | 1.479 (2n) |
| ⁴ B | 5 | 9 | 2- | _ | 0.969 |
| 4C | 6 | 8 | 0+ | 20.831 | 8.176 |
| 4N | 7 | 7 | 1+ | 7.551 | 10.554 |
| 40 | 8 | 6 | 0+ | 4.628 | 23.175 |
| 5 _B | 5 | 10 | 3/2- | 18.059 | 2.765 |
| 5C | 6 | 9 | 1/2+ | 21.080 | 1.218 |
| NC | 7 | 8 | 1/2- | 10.208 | 10.832 |
| 0 | 8 | 7 | 1/2- | 7.296 | 13.222 |

lived, the best way is to observe the quadrupole effects in the B-NMR spectra. The conventional β-NMR technique developed by K. Sugimoto et al.[Su66], and very much improved by T. Minamisono et al [Mi73], is well known to be very efficient for studying the magnetic interaction of nuclei with an external strong magnetic field. However, the method was not efficient for detecting quadrupole effects in β -NMR spectra due to the wide spread of NMR spectra caused by the quadrupole interaction. To improve the conventional β -NMR towards an efficient measurement of the quadrupole effects, some ingenious experimental techniques must be added to the NMR method, which is essentially based on the following four steps: 1) the production of polarized β -emitting nuclei through a nuclear reaction, 2) the preservation of its polarization by using a static strong magnetic field and implantation of polarized nuclei in a suitable media, 3) the observation of nuclear polarization based on the asymmetric β -ray distribution from the polarized nuclei, and 4) the resonant destruction of nuclear polarization by a radio-frequency (rf) magnetic fields. Furthermore for the success of the present quadrupole interaction studies, in addition to the above four steps, we must obtain well defined electric field gradients with which the nuclides interact. Such suitable fields must be looked for experimentally, for example, in various metal and /or insulator crystals. The quadrupole spectrum of a nuclide with nuclear spin *I* interacting with a unique electric field gradient at high field splits into 21 NMR-lines. This means that the detection of the one line among the 21 lines by an rf magnetic field gives only a partial destruction of the whole polarization. For example, such an partial NMR for I = 1 case is only one fourth of the case when a perfect destruction of polarization is obtained for the spin *I*. For the nuclides with higher spin I, the NMR effect is less detectable. In order to solve this experimental difficulty in the present study, an

ingenious new technique, the New Nuclear Quadrupole Resonance

5

technique (NNQR), was developed [So90, Mi93]. In this technique, all of the transition frequencies that correspond to a quadrupole coupling frequency, that is 2*I* rf's for spin *I*, are applied simultaneously during an rf application time in order to destroy the entire polarization. The NMR spectrum is detected as a function of coupling frequency. Here a set of 2*I* rf's is theoretically given for an electric quadrupole coupling frequency, if the Larmor frequency, the crystal orientation and the symmetry of the field gradients are known based on other experiments. The change in the polarization under the right quadrupole coupling frequency is maximum, and the original polarization is completely destroyed. With this new method, the efficiency of the NMR detection has been greatly improved; an one-day NNQR detection for the spin I = 1 case is equivalent to an entire month of measurement using the conventional technique. For the nuclides with higher spin *I*, therefore, the present NNQR is more efficient than the conventional β -NMR.

In addition to the measured coupling constant, we need to measure the electric field gradient at the probe nucleus experimentally, in order to extract the nuclear quadrupole moment from the coupling constant. This measurement is necessary because it is very difficult to estimate the electric field gradient theoretically in solid at the present stage where the environment surrounding the implanted nuclide is not known well. In the present study, we used proper crystals as implantation media containing stable isotopes of the implanted nuclei [Mi74]. Since the majority of the implanted nuclei that can be handled by the present NMR method sit in the substitutional sites of their isotopes in insulator crystals that contains the isotopes of the implanted nuclides, they are naturally exposed to the same electric field gradient that the stable isotopes are exposed to. Therefore the electric field gradient is measured by detecting the Fourier-Transformed NMR technique (FT-NMR) [Fu81] of each stable isotope in each crystals.

In this paper we report on studies concerning the quadrupole effects of ⁸Li in LiIO₃ and LiNbO₃, the effects of ¹²B and ⁸B in highly oriented BN and single crystal Mg and, finally, the effects of ¹²N in BN, GaN and AlN. We also report on the FT-NMR detection of ⁷Li in LiIO₃ and LiNbO₃, ¹¹B in BN, and ¹⁴N in BN and GaN crystals. Based on these results, the quadrupole moments of ⁸Li, ⁸B, ¹²B and ¹²N are deduced. Also, the NNQR technique and the first fruits produced by the newly developed method are given. In the following chapter (chapter 2), given are the definition of the quadrupole moment and a recent investigation of the quadrupole moment in the p-shell nuclei. The principle of the β-NMR detection is presented in chapter 3. The experimental set up is summarized in chapter 4. The experimental results are summarized in chapter 5. The results of the present experiment are discussed in chapter 6 in connection with the hyperfine interactions and the nucleon distribution in nucleus.

Chapter 2

THEORETICAL BACKGROUND CONCERNING THE ELECTRIC QUADRUPOLE MOMENTS

2-1 Quadrupole moments of A = 8 and 12 systems given by the jj model

The electric quadrupole moment is a measure of the extent to which the nuclear charge distribution deviates from spherical symmetry. The moment is defined by [Bo69]

$$Q = \left\langle I, M = I \middle| Q_{op} \middle| I, M = I \right\rangle , \qquad (2-1)$$

where the quadrupole operator is given by

$$eQ_{op} = \int \rho_{\epsilon}(\vec{r})r^2 (3\cos^2\theta - 1)dv , \qquad (2-2)$$

in terms of the charge density $(\rho_e(\vec{r}))$ in the nucleus.

In the shell-model description, for a single proton in an orbit (nlj), one obtains

$$Q_{sp} = \left\langle j, m = j \middle| r^2 (3\cos^2 \theta - 1) \middle| j, m = j \right\rangle$$

= $2 \langle jj20 \middle| jj \rangle \langle j \frac{1}{2} 20 \middle| j \frac{1}{2} \rangle \langle j \middle| r^2 \middle| j \rangle$
= $-\frac{2j-1}{2j+2} \langle j \middle| r^2 \middle| j \rangle$, (2-3)

where the radial average is given by

$$\left\langle j \left| r^2 \right| j \right\rangle = \int r^4 R_{nl}^2 dr \quad . \tag{2-4}$$

Here, R_{nl} is the radial wave function.

Since neutrons carry no electric charge in this model, the quadrupole moment vanishes for a single-neutron configuration. However, in fact, the nuclei that have a single-neutron configuration have finite values of the quadrupole moment. One good example is the ground state of $17O(I\pi)$ $= 5/2^{+}$). $(Q_{exp}(^{17}O) = -26mb, Q_{sp}(d_{5/2}) = -66mb [Bo69])$ This is because the nucleus cannot be described by such a simple configuration. The

configuration mixing of the nucleons must be considered in nuclei. The effective charge of a nucleon in a nucleus is introduced in order to include this effect. This effective charge has been investigated in every nuclear shell region to account for the quadrupole moment and the E2 electric properties, e.g., the transition probability of y-ray E2 transition. Since ⁸Li, ⁸B, ¹²B and ¹²N are odd-odd nuclei, it is thus necessary to consider an additivity rule by using simple angular momentum recoupling techniques [de63, He90]. If the proton and the neutron states are defined by $|j_p\rangle$ and $|j_n\rangle$ and their corresponding electric quadrupole moments are described by $Q(j_p)$ and $Q(j_n)$, respectively, the quadrupole moment of an odd-odd nucleus is obtained as follows using the assumption of weak coupling in obtaining the eigenstate $|j\rangle = |j_p \otimes j_n; j\rangle$:

$$Q(J) = \begin{pmatrix} J & 2 & J \\ -J & 0 & J \end{pmatrix} (-)^{J_{p}+J_{n}+J} (J) = \begin{pmatrix} J & 2 & J \\ -J & 0 & J \end{pmatrix} (-)^{J_{p}+J_{n}+J} (J) = \begin{pmatrix} J & 2 & J \\ J & J & J \\ J & J & J & 2 \end{pmatrix} \frac{Q(J)}{\begin{pmatrix} J_{p} & 2 & J \\ -J_{p} & 0 \end{pmatrix}}$$

with the experimental values.

This table shows that the single-particle description is not suitable for the electric quadrupole moment in this region at all. In this framework, the theoretical values for the present A = 8 system are all zero in spite of the large experimental values.

2J + 1)

$$\frac{(J_{p})}{J_{p}} + \begin{cases} J_{n} & J & J_{p} \\ J & J_{n} & 2 \end{cases} \frac{Q(J_{p})}{\begin{pmatrix} J_{n} & 2 & J_{n} \\ -J_{n} & 0 & J_{n} \end{pmatrix}} \end{bmatrix}. (2-5)$$

For an A = 8 isospin pair, the last two nucleons are in $p_{3/2}$ orbitals for both a proton and a neutron. For an A = 12 isospin pair, last nucleons are in p3/2 and p1/2 orbitals for a proton and a neutron, respectively, for ¹²B and, vice versa, for ¹²N. The electric quadrupole moments with a single particle description are thus calculated, and are shown in Table 2-1 along

Table 2-1 Quadrupole moments given by the single-particle model. Here, $\langle r^2 \rangle_p ^{1/2} = 2.5$ fm is assumed to calculate Q_{sp} . The sign of Q_{sp} for ¹¹B and ¹²B are suggested to the hole states $(\pi p^{3/2})^{-1}$.

| A | nucleus | Ιπ | Qsp (n | nb) Qexp | (m | b) | reference |
|----|-----------------|------|--------|-----------|----|------|-----------|
| 8 | ⁸ Li | 2+ | 0 | (+) 32.7 | ± | 0.6 | present |
| | 8B | 2+ | 0 | (+) 68.7 | ± | 2.1 | present |
| 11 | 11B | 3/2- | +25 | +40.59 | ± | 0.10 | [Su91] |
| | ¹¹ C | 3/2- | 0 | +33.27 | ± | 0.24 | [Su92] |
| 12 | 12B | 1+ | +10 | (+) 13.20 | ± | 0.25 | present |
| | 12N | 1+ | 0 | (+) 10.3 | ± | 0.7 | present |

2-2 Advanced shell-model description

Kitagawa and Sagawa performed a shell-model calculation for the nuclides in the 1p-shell region using the Cohen-Kurath and Millener-Kurath model with effective interactions CKPOT and CKI [Ki93a]. They employed the proton-neutron formalism in order to take into account the difference between protons and neutrons in the shell-model wave functions. The quadrupole moment is defined as a diagonal matrix element of the E2 operator:

$$M(E2) = \sum_{\pi} e_{p}^{eff} \left(\frac{1}{2} - t_{z,i}\right) r_{i}^{2} Y_{2,\mu}(\hat{r}_{i}) + \sum_{\nu} e_{\pi}^{eff} \left(\frac{1}{2} + t_{z,i}\right) r_{i}^{2} Y_{2,\mu}(\hat{r}_{i})$$
(2-6)

Here t_z is the isospin operator. The values of e_p^{eff} and e_n^{eff} are the effective charges of protons and neutrons in the nucleus, respectively. The quadrupole moment can be expressed by the one-particle spectroscopic factors as,

$$\begin{split} eQ &= \sum_{j_{1}, j_{2}, a_{c}, J_{c}, T_{c}, t_{sl}, t_{s2}} \sqrt{\frac{16}{5} \pi} \left\langle j_{1} \| r^{2} Y_{2} \| j_{2} \right\rangle \frac{1}{\sqrt{2J + 1}(2T + 1)} (-)^{T_{c} + \frac{1}{2} - T + 2J} \\ &\times \delta_{i_{sl}, i_{s2}} \left\langle t_{s1} \left\| \left\{ \begin{array}{c} e^{IS} \\ e^{IV} \tau_{3} \end{array} \right\} \right| t_{s2} \right\rangle \left\langle T_{C} M_{TC} \frac{1}{2} t_{s1} | TM_{T} \right\rangle^{2} \\ &\times \langle JJ 20 | JJ \rangle \left\{ \begin{array}{c} J & j_{2} & J_{C} \\ j_{1} & J & 2 \end{array} \right\} \\ &\times \left\langle JT \| a_{j_{1}}^{\dagger} \| a_{c} J_{c} T_{c} \right\rangle \left\langle a_{c} J_{c} T_{c} \| a_{j_{2}} \| JT \right\rangle \end{split}$$

where the isoscalar and isovector effective charges are defined as $e^{IS} = \frac{1}{2} \left(e_{\pi}^{eff} + e_{\nu}^{eff} \right)$ and $e^{N} = \frac{1}{2} \left(e_{\pi}^{\text{eff}} - e_{\nu}^{\text{eff}} \right)$

(2-7)

(2-8)

They used two kinds of single-particle wave functions, i.e., those in harmonic oscillator (HO) and in Woods-Saxon (WS) potentials. They considered the separation energy of the valence nucleon to account for the experimental values. The single-particle wave function for a valence nucleon was determined by adjusting the depth of the WS potential so as to reproduce the separation energy for each configuration. The effective charges were taken from empirical values, $e_p eff = 1.3e$ and $e_n eff = 0.5e$, given by the E2 giant quadrupole resonance in these region [Sa84]. The calculation are discussed along with the experimental value in Chapter 6.

Another investigation concerning the 1p-shell nuclei with the shellmodel description was carried out by Nakada et al. [Na93]. Their study was a development of the large-scale shell model by Wolters et al. [Wo90]. It involved a shell model calculation in $(0+2)\hbar\omega$ model space. They determined the wave functions in order to fit the experimental energy levels, including the binding energies, of the A = 4-16 nuclei. The advantage of their method is that since their description includes the configuration mixings up to 2hw, it is not necessary to introduce any effective charges. However, it must be noted that in their view a core

excitation (deformation) occurs considerably, even in the spherical region. This means that the wave functions that they used are not sufficiently suitable. Moreover, this model fails to reproduce the experimental nucleon radius determined by the interaction cross section [Sa94]. Further improvement on their model may be needed.

2-3 Known quadrupole moment values of ⁸Li and ¹²N

The discrepancy between the two data concerning the quadrupole moment O(8Li), i.e., one reported by Ackermann [Ac74] using the hyperfine interaction of ⁸Li in LiNbO3 and the other by Minamisono et al. [Mi75] using the hyperfine interaction in LiIO3, has been an open problem. It therefore prevents us from studying the nuclear structure of the nucleus. In order to solve this problem, we studied the hyperfine interactions of ⁸Li in both LiIO₃ and LiNbO₃ using a newly developed β -NMR method, New Nuclear Quadrupole Resonance technique (NNQR). Additionally, the electric field gradients for both the cases were measured by using the FT-NMR method for calibration.

Radutsukií et al. [Ra80] obtained the quadrupole moment of ¹²N from the analyses of the energy dependence of the cross section of the pion photoproduction near the threshold during studies of the ${}^{12}C(\gamma, \pi^+){}^{12}B$ and ${}^{12}C(\gamma, \pi){}^{12}N$ reactions. Using current algebra, the energy dependence of the cross section of these reactions can be also strongly connected with the electromagnetic properties of these nuclei. They deduced the quadruple moment of ¹²N as being $Q(^{12}N) = +49$ mb. However, since this result is far from any predictions obtained from the hyperfine studies [Mi72, Mi94], it has become necessary to measure the quadrupole moment by a more direct method. In this experiment, the quadrupole moment of 12N was measured spectroscopically for the first time. A comparison with these measured value will be made in chapter 6.

Chapter 3

EXPERIMENTAL METHOD

3-1 NMR

1) Nuclear magnetic resonance In a static magnetic field (H_0) , the Hamiltonian of a nuclear spin I with a magnetic moment of $\vec{\mu} = \gamma_N h \vec{l} = g \mu_N \vec{l}$ can be written as $H_{\rm M} = -\vec{\mu} \cdot \vec{H}_{\rm 0} = -g\mu_{\rm N}\vec{H}_{\rm 0} \cdot \vec{I} \ . \label{eq:HM}$ (3-1)The eigenstates of this Zeeman Hamiltonian are split into 21 states characterized by the magnetic quantum numbers m = I, I-1, ..., -I, i.e., $|-I\rangle$, $|-I+1\rangle$, ..., $|I-1\rangle$, $|I\rangle$. The energies of these states are $E_{M}(m) = -\mu H_{0}m$.

When a photon corresponding to the energy difference between the $|m\rangle$ and |m-1> substates are applied, a transition between these states occurs with the resonant absorption of a photon. For a pure Zeeman split, all of the resonance energies between neighboring states ($\Delta m = 1$) are equal. This resonance frequency is called the "Larmor frequency" v_L . Fig. 3-1 shows the energy levels as well as a resonance peak for a typical pure Zeeman Hamiltonian.

angular frequency of ω_L (Fig. 3-2),

$\omega_L = \gamma_N H_0 \ .$

For the NMR, a rotating magnetic field (H_1) perpendicular to an external field with an angular frequency of ω is applied to this system. In a rotating frame fixed to the H_1 field, the spin must rotate around the effective magnetic field (H_{eff}), as shown in Fig. 3-2. Here, H_{eff} is composed of H_1 and the reduced z component, $(\vec{H}_0 - \vec{\omega}/\gamma_N)$. If ω coincides with ω_L (the on

(3-2)

This phenomenon can be described by classical dynamics. A nuclear spin precesses around the direction of the external magnetic field with an

(3-3)

Energy levels in the Zeeman Hamiltonian for I=1.



Resonance frequency of the transition $\Delta m = 1$











Figure 3-2 Classical view of NMR: the spin movement in a magnetic field and resonance phenomena.

A spin is precessing around the external field H_0 by angular velocity ω_L

Rotating field $H_1(\omega_1)$ is applied perpendicular to $H_0(\omega_1 \sim \omega_L)$

In the rotating frame fixed to H_1 The spin is precessing around H_{eff}

When $\omega_1 = \omega_L$, the spin is precessing around H_1 : hence, $\langle J_z \rangle = 0$

resonance condition), the reduced z component of the spin becomes zero and, therefore, the spin should rotate around H_1 as shown in Fig. 3-2. As a result, the expectation value of the z-component of the spin becomes zero. The polarization (P) of a spin ensemble is defined along with the populations (a_m) of the magnetic substates (m) as

$$P = \frac{\langle I_z \rangle}{I} = \frac{1}{I} \sum_m m \cdot a_m , \qquad (3-4)$$

where the a_m are normalized as $\sum a_m = 1$. When a resonance is induced between two levels, the populations of both levels are equalized. For a pure magnetic interaction case, all of the substate populations are equalized simultaneously by applying the Larmor frequency and the polarization is destroyed completely as seen in Fig. 3-3.

2) Electric quadrupole interaction in high field

If an electric field gradient (q) interacts with the nucleus that has a quadrupole moment (Q), the Hamiltonian of this interaction can be written as follows

$$H_{Q} = \frac{eqQ}{4I(2I-1)} \left\{ 3I_{z}^{2} - I(I+1) + \frac{\eta}{2} \left(I_{+}^{2} + I_{-}^{2} \right) \right\}$$
(3-5)

Here, I_{\pm} are the ascending and descending operators along the defined zaxis. Also, the parameters of the electric field gradient are defined as $q = V_{zz}$

$$\eta = \frac{V_{xx} - V_{yy}}{V_{xx}} ,$$

$$|V_{x}| \gg |V_{yy}| \gg |V_{xx}| , . \qquad (3-6)$$

The X, Y and Z axes are the principal axes of the symmetrical tensor Vij = $\frac{\partial^2 E}{\partial \partial i}$. In this paper we call q the "electric field gradient" and η the

"asymmetry factor". In general, the principal axes of the electric field gradient are not necessarily identical to the external magnetic field. To transform the axes, the Euler angle is adopted, as shown in Fig. 3-4. With this transformation, the total Hamiltonian is described as follows:

magnetic substates



Figure 3-3 Quantum mechanical explanation of the NMR for polarized nuclear spin ensemble.

All substate populations are equalized. (P = 0)





$$H = H_{M} + H_{Q}$$

$$H_{M} = -\mu H_{0}I_{z}$$

$$H_{Q} = \frac{eqQ}{4I(2I-1)} \left[\left(\frac{3\cos^{2}\beta - 1}{2} + \eta\sin^{2}\beta\cos 2\gamma \right) \left\{ 3I_{z}^{2} - I(I+1) \right\} + \left(\frac{3}{4}\sin 2\beta - \frac{\eta}{4}\sin 2\beta\cos 2\gamma + i\frac{\eta}{2}\sin\beta\sin 2\gamma \right) (I_{+}I_{z} + I_{z}I_{+}) + \left(\frac{3}{4}\sin 2\beta - \frac{\eta}{4}\sin 2\beta\cos 2\gamma - i\frac{\eta}{2}\sin\beta\sin 2\gamma \right) (I_{-}I_{z} + I_{z}I_{-}) + \left(\frac{3}{4}\sin^{2}\beta + \frac{\eta}{4}(\cos^{2}\beta + 1)\cos 2\gamma - i\frac{\eta}{2}\cos\beta\sin 2\gamma \right) I_{+}^{2} + \left(\frac{3}{4}\sin^{2}\beta + \frac{\eta}{4}(\cos^{2}\beta + 1)\cos 2\gamma + i\frac{\eta}{2}\cos\beta\sin 2\gamma \right) I_{-}^{2} \right] .$$
(3-7)

When the electric quadrupole interaction is much smaller than the magnetic interaction, it can be treated as a perturbation. The energy of eigenstates can be written as

 $E_m = E_m^{(0)} + E_m^{(1)} + E_m^{(2)} + \cdots,$ order *i*. The unperturbed term $E_m^{(0)}$ is described as $E_m^{(0)} = \langle m | H_M | m \rangle$

$$= -\gamma_N \hbar H_0 m$$
$$= -h v_L m \qquad .$$

Under this condition, all of the resonance frequencies between the magnetic substates are the same with "Larmor frequency",

$$v_L = \frac{g\mu_N}{h} H_0 \ .$$

According to first-order perturbation calculation, the contribution to the energy of the magnetic substates m is given as

 $E_m^{(1)} = \langle m | H_0 | m \rangle$

 $=\frac{v_{\varrho}}{6}\left(\frac{3\cos^2\beta-1}{2}+\eta\sin^2\beta\cos^2\beta\right)$ where $v_{Q} = \frac{3eqQ}{2I(2I-1)h}$ is the coupling frequency of the quadrupole

interaction.

According to second-order perturbation calculation, the second order energy shift is given as,

$$(3-8)$$

where $E_{\rm m}(i)$ represents the contribution to the energy of the perturbation of

(3-9)

(3-10)

$$\cos 2\gamma \bigg| \big\{ 3m^2 - I(I+1) \big\} \bigg|,$$

(3-11)

$$E_m^{(2)} = \sum_m \frac{\langle m|H_Q|n\rangle\langle n|H_Q|m\rangle}{E_n - E_m}, \qquad (3-12)$$

where \sum_{m} means summation over *n*, except for $m (n \neq m)$. For nuclear spin I = 1, the second-order contribution for each magnetic substate (m) can be derived as

$$E_{1}^{(2)} = -E_{-1}^{(2)} = -\frac{1}{18} \frac{h v_{Q}^{2}}{v_{L}} (B+C)$$

$$E_{0}^{(2)} = 0 \qquad . \qquad (3-13)$$

Here,

$$B = \left(\frac{3}{4}\sin^2\beta + \frac{\eta}{4}(\cos^2\beta + 1)\cos 2\gamma\right)^2 + \left(\frac{\eta}{2}\cos\beta\sin 2\gamma\right)^2$$
$$C = \left(\frac{3}{4}\sin 2\beta - \frac{\eta}{4}\sin 2\beta\cos 2\gamma\right)^2 + \left(\frac{\eta}{2}\sin\beta\sin 2\gamma\right)^2 \qquad (3-14)$$

On the other hand, for a nuclear spin I = 2, the second-order contribution for each magnetic substate (m) can be derived as

$$E_{2}^{(2)} = -E_{-2}^{(2)} = -\frac{hv_{Q}^{2}}{v_{L}}(B+3C)$$

$$E_{1}^{(2)} = -E_{-1}^{(2)} = -\frac{hv_{Q}^{2}}{v_{L}}\left(\frac{B}{2} + \frac{5}{6}C\right)$$

$$E_{2}^{(2)} = 0$$
(3-15)

The changes in the energies for these first- and second-order perturbation calculations are schematically shown in Fig. 3-5. Finally, the transition frequency between m and m-1 substates is given as follows. Instead of a single Larmor line, 2I NMR lines (v_m) are observed,

$$v_{m} = \frac{E_{m-1} - E_{m}}{h}$$

= $v_{L} + v_{m}^{(1)} + v_{m}^{(2)}$ (3-16)

The first-order contribution in the frequency $(v_m^{(1)})$ is given by $v_m^{(1)} = \frac{E_{m-1}^{(1)} - E_m^{(1)}}{b}$

$$= -v_{\varrho} \left(m - \frac{1}{2} \right) \left(\frac{3\cos^2 \beta - 1}{2} + \eta \sin^2 \beta \cos 2\gamma \right).$$
(3-17)

They are distributed at constant intervals, and symmetrical around v_L as shown in Fig. 3-5.

The second-order contribution is also added as





nuclei perturbed by an electric quadrupole interaction.

Figure 3-5 Energy levels and transition frequencies for spin I = 1

$$v_m^{(2)} = \frac{E_{m-1}^{(2)} - E_m^{(2)}}{h}.$$
Each transition frequency for $I = 1$ is given by
$$(3-18)$$

$$v_1^{(2)} = v_0^{(2)} = \frac{1}{18} \frac{v_Q^2}{v_L} (B+C)$$
(3-19)

Regarding I = 2, they are given by

$$v_{2}^{(2)} = v_{-1}^{(2)} = \frac{v_{Q}^{2}}{v_{L}} \left(\frac{B}{2} + \frac{13}{6}C\right)$$
$$v_{1}^{(2)} = v_{0}^{(2)} = \frac{v_{Q}^{2}}{v_{L}} \left(\frac{B}{2} + \frac{5}{6}C\right)$$
(3-20)

Figures 3-6 and 3-7 show the resonance frequencies obtained in the firstand the second-order perturbation calculation as a function of the angle β .

3-2 β-NMR

In this experiment NNQR was detected by observing the asymmetric β decay of the polarized nuclei (β -NMR method) as the function of the quadrupole coupling frequency. It is essentially the same as the conventional β -NMR method used in previous studies concerning ¹⁷F [Mi74], and ¹²B [Mi78], except for the way that the rf field is applied for NMR or, in other words, the way of manipulating the spin ensemble. The essential parts of this method are summarized as follows:

1) Production of spin polarized $\boldsymbol{\beta}$ emitters through nuclear reactions

Polarized β -emitting nuclei are obtained by selecting the recoil nuclei that come out to a recoil angle relative to the incident beam of particle following a nuclear reaction. The ¹²B nuclei are produced through the ¹¹B (d, p) ¹²B reaction with a 1.5 MeV deuteron beam. The polarization reaches 12% at a recoil angle of 40 ± 5 degrees relative to the direction of the incident beam [Ta76]. The ¹²N nuclei are produced through the ¹⁰B



Figure 3-6 Angle dependence of the resonance frequencies perturbed by an electric quadrupole interaction for spin I = 1. (a) Single quantum transition. (b) Double quantum transition.



Angle (β) between q and H_0 (degree)

Figure 3-7 Angle dependence of the resonance frequencies perturbed by an electric quadrupole interaction for spin I = 2.

 $(^{3}\text{He}, n)$ ¹²N reaction at 3.0 MeV. The polarization reaches 20% at 20 ± 5 degrees. The ⁸Li nuclei are produced through the ⁷Li (d, p) ⁸Li reaction at 3.5 MeV with polarization of about 12% at 13 ± 5 degrees. The ⁸B nuclei are produced through the ⁶Li (³He, n) ⁸B reaction at 4.7 MeV with polarization of about 6% at 13 ± 5 degrees.

The conditions for the production of these unstable nuclei are summarized in Table 3-1. The direction of the produced polarization is normal to the reaction plane formed by the incident beam and the recoil nucleus as shown in Fig. 3-8.

2) Preservation of the spin polarization in crystals Recoil atoms ejected from the target are in various charge states. During flight in the vacuum, the nuclei interact with the strong hyperfine fields given by the atomic configurations, and the polarization of the nuclei is quickly destroyed if this interaction is not decoupled. In order to maintain the polarization, a magnetic field that is sufficiently strong to decouple the hyperfine interaction between the nucleus and its atomic hyperfine fields is applied. In the present experiment, a high static magnetic field (Table 3-1) is applied parallel to the direction of the nuclear polarization in order to maintain it during the flight. Also, this high field is sufficiently strong to decouple hyperfine interactions due to various defects or radiation damages created in the crystal at room temperature during the last stage of implantation.

In order to achieve NMR detection, the recoil nuclei are implanted into a catcher crystal to stop them in it and to expose them in a well defined electric field gradient. Implanted nuclei are mainly located in a substitutional site of the stable isotopes in the insulator crystal. The ⁸Li nuclei was located in a Li site, the ¹²B nuclei in a B site and the ¹²N nuclei in a N site. The polarization of the implanted nuclei located in the



Table 3-1

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Experimental conditions for the production of polarized nuclei

| T I I | ⁸ Li | 8B | 12 _B | 12 _N | |
|-----------------------|-----------------|--------------|-----------------|------------------|--|
| Half life $(T_{1/2})$ | 838 (6) msec | 770 (3) msec | 20.20 (2) msec | 11.000 (16) msec | |

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| Reaction | ⁷ Li (d, p) ⁸ Li | ⁶ Li (³ He, n) ⁸ B | ¹¹ B (d, p) ¹² B | ^{10}B (^{3}He , n) ^{12}N |
|--------------------|--|--|--|------------------------------------|
| Q-value | –0.189 MeV | -1.974 MeV | 1.149 MeV | 1.572 MeV |
| Beam Energy | 3.5 MeV | 47 MeV | 1.5 MeV | 3.0 MeV |
| Recoil angle | 13 ± 8 ° | 13 ± 8 ° | 40 ± 8 ° | 20 ± 8 ° |
| Mean Recoil Energy | 0.7 MeV | 1.0 MeV | 0.2 MeV | 0.7 MeV |
| Stopper | Pt, LiIO ₃ , LiNbO ₃ | Pt, Mg | Pt, Mg, BN, Mylar | Pt, BN, GaN, AlN, Mylar |
| Max Range | 1.6 µm | 3.4 µm | 0.9 µm | 2.7 μm |
| Magnetic field | 4000.0 Oe | 7000.0 Oe | 5000.0 Oe | 5000.0 Oe |
| Polarization | 12% | 6% | 12% | 17% |
| | | | | |

interstitial site or substitutional site of other elements are found destroyed due to mainly by the paramagnetic interactions with unpaired electrons.

3) Detection of polarization

Nuclear polarization is observed by detecting the asymmetric distribution of β rays emitted from polarized nuclei. The angular distribution of β rays is asymmetric if the nuclei are polarized, due to parity non conservation in the weak interaction. It is given as [Mo73]

 $W(\theta) = 1 + (\frac{v}{c})AP\cos\theta,$

where θ is the angle between the direction of the emitted β ray and the polarization axis. A is the asymmetry parameter that is determined from the β -decay theory, v/c is the ratio of the velocity of the β particle to the light velocity, and P is the nuclear polarization. Since the mean energy of the β ray from the A = 8 and 12 systems are high, about 5 and 8 MeV, respectively, the ratio v/c is about 1.

(3-21)

The asymmetry parameter is given as [Mo73]

$$A = \pm \lambda_{ii'} \frac{|C_A|^2 |\int \sigma|^2}{|C_V|^2 |\int 1|^2 + |C_A|^2 |\int \sigma|^2} - 2\delta_{ii'} \sqrt{\frac{i}{i+1}} \frac{C_A C_V \int \sigma \int 1}{|C_V|^2 |\int 1|^2 + |C_A|^2 |\int \sigma|^2}, \quad (3-22)$$

where the upper sign refers to β^+ decay and the lower sign to β^- decay, respectively. The coefficient $\lambda_{ii'}$ is $\lambda_{ii} = 1$ for $i \to i = i - 1$

$$\frac{1}{i+1} \text{ for } i \to i = i$$

$$\frac{-i}{i+1} \text{ for } i \to i = i+1 , \qquad (3-23)$$

where <1> is the Fermi matrix element, C_V the Fermi coupling constant, < σ > the Gamow-Teller matrix element, and C_A the Gamow-Teller coupling constant. The β decay of ¹²B and ¹²N are pure Gamow-Teller transitions (Fig. 3-9) [Az90]. Their asymmetry parameters are $A = \pm 1$, where the + sign denotes ¹²N and the – sign ¹²B. On the other hand, the β decays of ⁸Li and ⁸B are mixed with a Gamow-Teller transition and a



Figure 3-9 Energy-level schemes of A=12 system

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Fermi transition (Fig. 3–10) [Aj88]. However, the mixing of a Fermi transition is negligibly small [Tr75]. Their asymmetry parameters are $A = \pm 1/3$, where the + sign denotes ⁸B and the – sign ⁸Li.

In an actual measurement, it has been observed the ratio R_{off} of the β -ray counting rates from the counters that are located above and below the catcher relative to the polarization direction, without any operation to the spin ensemble (NMR):

$$R_{off} = \frac{N_u}{N_d}$$
$$= \frac{\varepsilon_u (1 + AP)}{\varepsilon_d (1 - AP)} . \tag{3-24}$$

Here, N_u and N_d are the β -ray counts for the upper ($\theta = 0^\circ$) and lower ($\theta = 180^\circ$) counters, respectively. ε_u and ε_d are the geometrical and instrumental efficiencies for the upper and low counters, respectively. When the polarization is completely destroyed by an rf field, the ratio R_{on} given as

$$R_{on} = \frac{\varepsilon_u}{\varepsilon_d}$$
 (3-25)

Therefore, a ratio between these counting rate ratio (R_{on} and R_{off}), the β ray asymmetry change due to the rf is derived as follows (the NMR effect),
if $|AP| \ll 1$ is satisfied, $\Delta R = \frac{R_{on}}{R_{off}}$

| 1 + AP | |
|-------------------|--------|
| $=\frac{1}{1-AP}$ | (2.20) |
| $\cong 1 + 2AP$ · | (3-26) |

4) Resonant destruction of polarization by rf magnetic fields (NMR) The typical time sequence program of a β-NMR experiment is shown in Fig. 3-11. The rf field for the NMR is applied after the beam-on irradiation time and is followed by a β-ray counting time. While the rf field (intensity: H₁) is being applied, the time development of the polarization (P) is given by the following differential equation:



 $I^{\pi}=2^{+}$

8⁸B

979.TJ

2+

16.63

⁸Li

16.004

T₁₁₂=770±3msec

 $Q_{EC}=17.98 \text{MeV}$

Figure 3-10 Energy-level schemes of A=8 system

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T_{1/2}=838±6msec

rπ=2⁺

Qβ=16.00MeV





$$\frac{dM_z}{dt} = \tilde{q}\mu P_0 - \left(\Lambda + \lambda + \pi\gamma_N^2 H_1^2 f\right)$$
$$\frac{dn}{dt} = \begin{cases} \tilde{q} - \lambda n & (0 \le t \le t_1) \\ -\lambda n & (t \ge t_1) \end{cases}$$

$$P = P_0 \frac{\lambda^2}{LL'} \frac{(1 - e^{-\lambda t_1})(1 - e^{-\lambda t_4})}{(1 - e^{-\lambda t_1})(1 - e^{-\lambda t_4})} \frac{e^{-\lambda t_4}}{e^{-\lambda t_4}}$$

Here, L and L' are defined as $L = \lambda + \Lambda + \frac{2\gamma_N^2 H_1^2}{\Delta\omega} \tan^{-1} \left(\frac{\Delta\omega}{2\delta}\right)$ $L' = \lambda + \Lambda$

where δ is the half width at half maximum (HWHM) of the line-shape function, which is assumed to be Lorentzian, $\Delta \omega$ is a modulation width of the applied rf field.

5) Adiabatic fast-passage (AFP) method Applying a rotating rf magnetic field H_1 of angular frequency ω to a spin perpendicular to the strong static magnetic field H_0 , the rotation of the spin can be described by use of the rotating frame that rotates with the same angular velocity of rf field. In the rotating frame, the effective magnetic field is given by $\bar{H}_{eff} = \bar{H}_0 + \frac{\bar{\omega}}{\gamma_0}$ as shown in Fig. 3-12. The spin is

 $f(\omega))M$

(3-27)

where M_z (= $n\mu P_0$) is the total magnetization, \tilde{q} the production rate of the polarized nuclei, μ the nuclear magnetic moment, P_0 the initial polarization, Λ the reciprocal of the spin-lattice relaxation time (T_I) , λ the reciprocal of the lifetime of the nucleus, w the gyromagnetic ratio of the nuclei, $f(\omega)$ the line-shape function of the resonance, n the number of nuclei per unit volume, and t₁ the beam irradiation time (Fig. 3-11). The first equation gives the time development of the total magnetization, in which effects that come from the rf field, spin lattice relaxation, and nuclear decay are taken in. The second equation gives the number of the β emitting nuclei. The time dependent polarization is given as follows: -L14 -L' 13 $-\lambda(t_2+t_3)$ (3-28)

(3-29)



Figure 3-12 Adiabatic fast-passage (AFP) method. The axes are fixed to the rf (H_1) rotating flame. It supposes the shape of rf rectangle. The appreciable reduction of the polarization is occurred through the spin inversion.

 $P' = P \cos \xi \cdot \cos \xi'.$

trapped in and precesses around this effective field H_{eff} . First, put the ω far away of ω_L and drug it slowly toward ω_L and the spin direction follows H_{eff} . Therefore, if ω is swept across ω_L , the direction of the spin is inverted (Fig. 3-12). This method is called the "Adiabatic Fast Passage" method [Ab61]. The method was introduced to the conventional β -NMR method by Minamisono [Mi73]. To perform this operation, the intensity of H_1 and the sweep rate of the frequency must satisfy the following condition,

 $\frac{d\omega}{dt} \ll (\gamma_N H_1)^2 .$

must be satisfied,

 $\gamma_N H_1 > 2\pi D$.

The former relation is derived based on the condition that the effective field changes far slowly compared with the spin rotation. The latter relation means that the applied oscillating field is sufficiently larger than the dynamic dipole magnetic field.

The achievement of spin inversion by the AFP method depends on the rf intensity as a function of time. If a constant H_1 is used, the achievement of inversion is deduced showing in Fig. 3-9. Up on applying on rf field, the spin precesses around H_{eff}^{i} and the expectation value is equal to the projected value to H_{eff}^{i} . The expectation value of the spin along H_{eff} is maintained during a frequency sweep if the equations given above are satisfied. Up on stopping rf field, the spin is projected back to the direction of the external field. Then, the achievement ε of the inversion is given by $\frac{-\frac{\omega_z}{\gamma_N}}{\left(\frac{2}{2}\right)^2 + H_1^2}$ (3-32)

$$\varepsilon = \frac{H_0 - \frac{\omega_1}{\gamma_N}}{\sqrt{\left(H_0 - \frac{\omega_1}{\gamma_N}\right)^2 + H_1^2}} \frac{H_0 - \frac{\omega_2}{\gamma_N}}{\sqrt{\left(H_0 - \frac{\omega_2}{\gamma_N}\right)^2 + H_1^2}}$$

It is evident that a constant H_1 with narrow range of frequency modulation (FM) can not invert spin perfectly. In order to achieve

(3-30)

Furthermore, in a crystal there exists the dynamic (time dependent) fluctuation of magnetic field due to the surrounding nuclear magnetic moment (D). In order to decouple this interaction, the following condition

(3-31)

complete inversion, an amplitude modulated (AM) rf is employed so as to minimize any reduction of the projection at both the beginning and end of the rf application as shown in Fig. 3-13. It is known that the influence of AM and the frequency can be neglected under the conditions of this experiment.

6) Modified β -NMR for measuring the electric quadrupole coupling frequency (v_Q) — NNQR method

If one limit interest to only β -NMR, detection of the quadrupole interactions of short-lived β -emitting nuclei is usually more difficult and time consuming than the conventional β -NMR detection of a pure magnetic interaction. In order to cope with these difficulties, the method must be improved so as to enable the detection of the coupling constant both easily and efficiently.

It is very difficult to observe a split spectrum due to the electric quadrupole interaction by detecting the β -NMR, as shown in the following. Consider the case when a split line is saturated by an rf, the polarization change is very small (Fig. 3-14). It is only $3/2 \times \{I(I+1)(2I+1)\}^{-1}$ of the total polarization for the nuclide with spin *I* when the population differences of the neighboring magnetic substates are equal as shown in Fig. 3-14. For the case of I = 1 and I = 2, it is 1/4 and 1/20 of total polarization, respectively. To overcome this difficulty we decided to saturate all lines simultaneously applying all transition rf fields given by a quadrupole coupling constant in order to perfectly destroy the polarization. An outline of this method is given in Figs. 3-15a and 15b.

If the Larmor frequency and the field gradient as well as its orientation relative to H_0 are known, all of the 2*I*-transition frequencies for a given electric quadrupole coupling constant can be calculated for a nucleus at a high field. Any change in the nuclear polarization is detected as a function



Figure 3-13 Optimum rf amplitude modulation (AM) for the AFP technique. The axes are fixed to the rf (H_1) rotating flame. It shows that the reduction of the polarization due to the spin inversion is small. $P' \cong P$



Figure 3-14 Difference between partial and complete depolarization. Single rf can induce just one of two transitions. The polarization change due to partial depolarization is only 1/4 of complete depolarization.



operation (NNQR method). The case of the spin I = 2transitions are occurred.

Figure 3-15a Principle of the newly developed multiple rf If the intensity of $rf(H_1)$ is enough high, the double quantum



Figure 3-15b Principle of the newly developed multiple rf operation (NNQR method). The case of the spin I = 1. If the intensity of rf (H_1) is enough high, the double quantum transition is occurred at eqQ/h = 0.

of the coupling constant (Figs. 3-15a and 15b). The polarization can be completely destroyed if all of rf fields corresponding to a true quadrupole coupling constant are applied and the transitions are saturated. This complete destruction of polarization is in vivid contrast with the partial destruction upon applying a single rf field for the conventional β -NMR method described above. In the conventional method, furthermore, 21 transitions have to be detected in order to measure the coupling constant. The spectrum of this operation has a characteristic shape (Figs. 3-15a and 15b). A resonance of the partial destruction occurs, i.e., outer applied rf fields resonate with the inner lines (Fig. 3-15a). A double quantum transition also causes a distortion of the spectrum (Figs. 3-15a and 15b). Since the spin of ¹²B and ¹²N is 1, although it does not consider the former complication, the latter contribution can affect the spectrum shape (Fig. 3-

15b).

Given a quadrupole coupling constant (v_0) , 2I transitions at high field are calculated for spin I provided that the Larmor frequency (v_L) and the asymmetry factor (η) and its orientation (β and γ) are given (see the section "2) Electric quadrupole interaction" in this chapter).

Here, we assume that the Larmor frequency, asymmetry factor of the electric field gradient, Euler angles between the electric field gradient and the external magnetic field are know from other experiments. The asymmetry factors of all crystals used in this experiment are zero due to the symmetry ambient distribution around Li, N, and B sites. The angle β is known based on the setting of the sample relative to the external field. Larmor frequency (v_L) was derived based on the double quantum transition (DQ) between m = 1 and -1 for ¹²B and ¹²N. The frequency of DQ (v_{DQ}) is not equal to v_L if the quadrupole interaction is not sufficiently smaller than the magnetic interaction (Fig. 3-5). Given the quadrupole coupling frequency, v_L can be calculated from v_{DQ} .

As for ⁸Li and ⁸B, since the polarization change by the double quantum transition $(m = 1 \leftrightarrow -1)$ is small, Larmor frequency (v_L) of these nuclei were derived from the transition frequency at magic angle $\beta_M = \cos^{-1} \sqrt{\frac{1}{3}}$. In this condition, all of the transition frequencies coincide if the secondorder perturbation is negligible (Fig. 3-7). Given the quadrupole coupling frequency, v_L can be calculated from v_{DQ} .

3-3 Causes of the line broadening of the NMR spectra

There are many interactions which can affect the NMR spectrum, and are important for analyzing it. In this section we summarize these interactions:

1) Dipole-dipole interaction

The nucleus in the solid is surrounded by host nuclei. If these nuclei have magnetic-dipole moments, they cause a dynamic magnetic field at the nucleus. The Hamiltonian of this dipole-dipole interaction between two nuclei (Fig. 3-16) is given as [Ab61]:

$$W_{12} = \frac{\gamma_1 \gamma_2 \hbar^2}{r_{12}^3} \left\{ \vec{I}_1 \cdot \vec{I}_2 - 3 \frac{\left(\vec{I}_1 \cdot \vec{r}_{12}\right) \left(\vec{I}_2 \cdot \vec{r}_{12}\right)}{r_{12}^3} \right\} , \qquad (3-33)$$

where r_{12} is the distance between two nuclei; γ_1 and γ_2 are the gyromagnetic rations of the probe and host nuclei. It can be seen that the host nuclei produce a local field (H_{12}) at the site of any implanted nuclei, $W_{12} = -\bar{\mu}_2 \bar{H}_{12}$

$$= -\gamma_2 \hbar \vec{I}_2 \cdot \vec{H}_{12} . \tag{3-34}$$

Because host nuclei have thermal vibration, this interaction causes a dynamic magnetic field at a nucleus site. The resonance line is thus broadened due to this contribution.

The Hamiltonian of the dipole-dipole interaction between like spins can be decomposed as follows [Ab61]:



$$W_{i\vec{x}} = \frac{\gamma_N^2 \hbar^2}{r^3} \left\{ \vec{i} \cdot \vec{i}' - 3 \left[i_z \cos \tilde{\beta} + \sin \tilde{\beta} \left(i_x \cos \tilde{\gamma} + i_y \sin \tilde{\gamma} \right) \right] \left[\vec{i}_z \cos \tilde{\beta} + \sin \tilde{\beta} \left(\vec{i}_x \cos \tilde{\gamma} + \vec{i}_y \sin \tilde{\gamma} \right) \right] \right\}$$
$$= \frac{\gamma_N^2 \hbar^2}{r^3} (A + B + C + D + E + F)$$

where

$$\begin{cases} A = i_{z}\vec{i}_{z} \left(1 - 3\cos^{2}\tilde{\beta}\right) \\ B = -\frac{1}{4} \left(1 - 3\cos^{2}\tilde{\beta}\right) (i_{+}\vec{i}_{-} + \vec{i}_{-}i_{+}) = \frac{1}{2} \left(1 - 3\cos^{2}\tilde{\beta}\right) (i_{z}\vec{i}_{z} - \vec{i} \cdot \vec{i}') \\ C = -\frac{3}{2}\sin\tilde{\beta}\cos\tilde{\beta}e^{-i\tilde{\gamma}} (i_{z}\vec{i}_{+} + \vec{i}_{z}i_{+}) \\ D = C^{*} = -\frac{3}{2}\sin\tilde{\beta}\cos\tilde{\beta}e^{i\tilde{\gamma}} (i_{z}\vec{i}_{-} + \vec{i}_{z}i_{-}) \\ E = -\frac{3}{4}\sin^{2}\tilde{\beta}e^{-2i\tilde{\gamma}}i_{+}\vec{i}_{+} \\ F = E^{*} = -\frac{3}{4}\sin^{2}\tilde{\beta}e^{2i\tilde{\gamma}}i_{-}\vec{i}_{-} \end{cases}$$
(3-35)

Here, $\tilde{\beta}$ and $\tilde{\gamma}$ are polar coordinates of vector \vec{r} , which describes their relative positions, the z-axis being parallel to the applied external field (Fig. 3-16). Only terms A and B can contribute to the dynamic field. Term A describes the effect of the static local field mentioned above. Term B shows a simultaneous reversal of two neighboring spins in opposite directions, called a "flip-flop". The latter is important in an interaction between like spins.

Using the method of moments, any line broadening due to a dipole-dipole interaction can be deduced [Ab61]. The *n*th moment (M_n) is defined as $M_n = \int (\omega - \omega_0)^n f(\omega) d\omega ,$ (3-36)

where $f(\omega)$ is a normalized shaped function with a maximum at a frequency ap. A Gaussian curve is described by a normalized function,

$$f(\omega) = \frac{1}{\Delta\sqrt{2\pi}} e^{\left(\frac{-(\omega-\omega_0)^2}{2\Delta^2}\right)},$$
(3-37)

from which a relation between the nth moments and the line width can be derived as

 $M_2 = \Delta^2, M_4 = 3\Delta^4, ..., M_{2n} = 1 \cdot 3 \cdot 5 \cdots (2n-1)\Delta^{2n},$ in which the odd moments vanish. The half width at half-maximum

intensity (δ) (HWHM) turn out to be

 $\delta = \Delta \sqrt{2\log 2} = 1.18\Delta \ .$

Here, we treat the condition in which the host and probe spins are alike. The second moment with the surrounding dipoles is expressed as follows

Van Vleck formula):

$$M_{2} = \overline{\Delta \omega}^{2}$$

$$= \frac{1}{3} \gamma_{N}^{4} \hbar^{2} I(I+1) \sum_{k} \left(\frac{3}{2} \frac{1-3}{2} \right)$$

$$= \frac{3}{4} \gamma_{N}^{4} \hbar^{2} I(I+1) \sum_{k} \frac{(1-3)}{r}$$

average $(1-3\cos^2\tilde{\beta}_{jk})^2$ over all directions, leading to $M_2 = \frac{3}{5} \gamma_N^4 \hbar^2 I(I+1) \sum_{k} \frac{1}{r_{ik}^6} \, .$

When the host spins are not unlike those of the probe, the second moment is altered as

$$M_{2} = \frac{1}{3} \gamma_{1}^{2} \gamma_{2}^{2} \hbar^{2} I_{2} (I_{2} + 1) \sum_{k} \frac{(1 - 3)}{2} \frac{1}{3} \frac{1}$$

written as

$$\overline{\Delta\omega}^2 = F_L(I)\gamma_N^4 \hbar^2 \sum_k \left(\frac{3}{2} \frac{1 - 3\cos^2 \bar{\beta}_{jk}}{r_{jk}^3} + F_L(I) = \frac{4}{27}I(I+1) + \frac{2I^2(I+1)^2 + 3I(I+1)}{18(2I+1)}\right)$$

From these relations, the line broadening due to any dipole-dipole interactions from surrounding nuclei can be estimated. The calculated dipolar broadenings of the samples used in this experiment are listed in Table. 3-2.

(3-38)

$$\frac{\cos^2 \tilde{\beta}_{jk}}{\int_{jk}^3}\right)^2$$

(3-39)

For a polycrystalline having random orientation it is permissible to

(3-40)

$$\frac{\cos^2 \tilde{\beta}_{jk}}{r_{jk}^6}^2 \qquad (3-41)$$

Furthermore, when a quadrupole interaction exists, the second moment is altered even more. If both the probe and host spins are the same and experience the same electric field gradient, the second moment can be

$$\frac{\cos^2 \tilde{\beta}_{jk}}{\frac{3}{k}}\right)^2 + 3I(I+1) + 1$$

Table 3-2

Calculated dipolar broadenings of the samples.

| media | crystal structure | site | <i>ДН</i> (Ое) |
|-------------------|-------------------|------|-----------------------|
| LiIO ₃ | hexagonal | Li | 2.2 |
| LiNbO3 | Ilmenite | Li | 0.9 |
| hexagonal BN | hexagonal layer | В | 1.7 |
| | | Ν | 4.0 |
| GaN | Wurtzite | N | 2.7 |

2) Spread in the electric field gradients

Many defects in the stopper sample are caused during the process of implantation. Even though implanted nuclei cause many defects before stopping, the final sites of the implanted nuclei can be considered to be far from these [Mi74]. If there is a defect near to the final site, any implanted nuclei are perturbed by a strong field gradient, perhaps destroying their polarization. The contributions from defects on the electric field gradient at an implanted nucleus are added to the proper one. The electric field gradient at an implanted nucleus are then distributed around a proper value. This was observed in many cases, for example 17F in MgF₂ [Mi74] or ⁴¹Sc in TiO₂ [Mi93]. In these studies, the deviation of the field gradient was $\Delta q/q = 5 \sim 10\%$ at HWHM.

3) Intensity of the rf field

The finite intensity of rf field causes the resonance spectrum to spread. In order to simplify the situation, a delta function is assumed as the resonance shape. In the rotating flame fixed to the rotating field (H_1) that is near to the Larmor frequency, $\omega = \omega_L + \Delta \omega$, the spin rotates along the effective field (Fig. 3-2). The expectation value along this field is reduce by factor of ζ ,

$$\zeta = \cos \xi = \frac{\Delta \omega_{\gamma_N}}{\sqrt{\left(\Delta \omega_{\gamma_N}\right)^2 + H_1^2}} \ .$$

After applying an rf field, the polarization is reduced by factor of ζ^2 . Calculations of the spectrum with any intensity of the rf field for ¹²N at H_0 = 5kOe are shown in Fig. 3-17. It causes Δ (HWHM) = 1.8 kHz for H_1 = 5 Oe. If the applied rf field consists of many pulses, the destruction is repeated and the width of the obtained spectrum becomes wider. Fig. 3-18 shows two cases (1 pulse and 5 pulses), each condition of the rf field is the same except for the number of rf fields.

4) Chemical shifts

In a magnetic field, atomic electrons cause a static field at the nucleus. The magnetic field felt by the nucleus is different from the external one. This shift of the magnetic field at the nucleus is called a chemical shift. If the electrons constitute closed shells, the orbital motions in the external magnetic field produce a diamagnetic field at the inner nucleus. On the other hand, admixtures with exited orbital states produce a paramagnetic field. The former is called a diamagnetic shift, and the latter is called a paramagnetic shift. The amount of the these shifts is proportional to the external field. They depend on the electric structure of the surroundings of the nucleus. It is therefore very difficult to estimate these chemical shifts in a solid because of the difficulty for estimation of the electronic structure in a solid.

In a metal, free electrons produce a local field at the probe nucleus, i.e., a Fermi contact interaction occurs between these *s*-like free electrons and

(3-43)





Figure 3-17 Effect of strong rf field on the resonance shape. This is the case of ^{12}N . It is supposed that the inherent resonance peak is the delta function.



Figure 3-18 Effect of multiple rf field on the resonance shape. This is the case of ^{12}N . It is supposed that the inherent resonance peak is the delta function and $H_1 = 0.5$ Oe.

frequency $\Delta v = v - v_L$ (kHz)
the nucleus. This shift of the magnetic field in metals is called a Knight shift. The amount of the shift is proportional to the external field.

In this study, probe nuclei were implanted in a metal, a semiconductor, and an insulator. The shifts of the magnetic field in these materials are expected to be different from one another. Although they do not cause any appreciable broadening in the resonance spectrum, it is very important to know the Larmor frequency in the new rf operation (NNQR method), as described above (Chapter 3-1-6). We thus observed all of the Larmor frequencies of the probe nuclei in each media.

3-4 Implantation media

In the electric field gradient, atomic electrons' motions are perturbed (Sternheimer polarization) and cause an additional electric field gradient at the inner nucleus. Although this has been well studied in free atoms [St50, St85], it is very difficult to estimate this effect in a solid due to the complicated influence of the environmental electronic structure. In this study, in order to avoid this difficulty, probe nuclei were implanted in media which included their stable isotopes. The electric field gradient of the isotope is equal to that at the implanted nucleus, due to the same environmental electronic structure. The electric field gradients can therefore be deduced from the observed electric quadrupole coupling constant of the isotopes with their known quadrupole moments.

In the following we summarize the catcher media used in this experiment. These media have isotope elements of implanted nuclei, except for the case of ⁸B. The electric field gradient at the implanted nuclei is obtained from NMR studies of its stable isotopes. In the case of ⁸B, its electric field gradient can be found by studying the hyperfine interactions of its isotope ¹²B in Mg metal.

In order to obtain the electric quadrupole moment, although we need information concerning the electric field gradient, it is very difficult to estimate it in solids. We therefore utilized the field gradient of a substitutional nitrogen site that could be deduced from the NMR of the stable isotope ¹⁴N.

1) h-BN (hexagonal Boron Nitride)

This sample was used for measuring the quadrupole moment of both ¹²B and ¹²N. The crystal structure of this material is a hexagonal boron nitride structure, like that of graphite (Fig. 3-19) [Wy82]. The electric field gradients at the boron and nitrogen sites are parallel to the *c*-axis. It is an insulator, and is easily cleft perpendicular to the *c*-axis. Since it is very difficult to make a large single-crystal lump, we obtained a highly oriented crystal sample from the Denki Kagaku Kogyo [De].

The distribution of the *c*-axis of this sample is shown in Fig. 3-20. It was measured by reflecting X-rays at the Bragg angle (26.6 degree) relative to the direction of X-ray incidence (Fig. 3-21) [Su90, Wa86]. The effect on the NMR spectrum due to the distribution is discussed later.

The electric structure of BN has been investigated [Hu85, Ca87, Or90, Ga 93]. The electric quadrupole coupling constant at the boron site was reported by Silver and Conor. Silver reported on the cw-NMR of powder BN at room temperature [Si60] leqQ/h (¹¹B in BN)I = 2.96 ± 0.10 MHz and $\eta = 0$ based on the crystal structure. Conor determined it by using newly developed equipment [Co90]. They measured the NQR spectrum of ¹¹B in BN at 4.2K using a SQUID spectrometer, leqQ/h (¹¹B in BN; 4.2K)| = 2934 \pm 4 kHz and η = 0.0. However, we have not adopted this value, since the measuring temperature was so very far different. As for a nitrogen, there is no information concerning the electric field gradient. We



Figure 3-19 Crystal structure of hexagonal boron nitride (h-BN)





Figure 3-20 Distribution of the *c*-axes of a highly oriented BN sample.



Figure 3-21 X-ray reflection method used to measure the distribution of the c-axes in a highly oriented BN sample. In this condition, when the c-axis is parallel to the X-ray direction, the intensity of the reflected X-ray is maximum at the angle 26.6°.

measured electric field gradients at both the boron and nitrogen sites by a pulsed FT-NMR method.

2) GaN (Gallium Nitride) The crystal structure of this material is the wurtzite structure and the field gradient at the nitrogen site is parallel to the *c*-axis and the asymmetry parameter $\eta = 0$ (Fig. 3-22) [Wy82]. This material is known to be a semiconductor having a large energy gap. It is expected to be used for a blue light LED.

The single crystal is obtained by the MOCVD (Metal Organic Chemical Vapor Deposition) method [It85] from MATSUSHITA Electronics Company[Ma]. It was grown on a (0001)-oriented sapphire (α -Al₂O₃) substrate. The thickness of the GaN layer is 15 ~ 30 µm, sufficiently thick to implant ¹²N nuclei.

Although the electric structure of GaN has been studied by many authors [Hu85, Go91, Pe92], there is no information concerning the electric quadrupole coupling constant for nitrogen. Hee Han has reported the electric quadrupole coupling constant at the Ga site as being eqQ/h $(^{69}Ga \text{ in } GaN) = 2.8 \text{ MHz}, eqQ/h (^{71}Ga \text{ in } GaN) = 1.7 \text{ MHz} [Ha88].$ The electric field gradient of GaN at the nitrogen site was measured by a pulsed FT-NMR method.

3) AlN (Aluminum Nitride)

The crystal structure of this material also is a wurtzite structure [Wy82]. Although we can not obtain a single-crystal sample, we can use a polycrystal sample. This type sample is offered by KAWASAKI SEITETSU [Ka] as a plate.

The electric structure of AlN has also been studied [Hu85, Ch93]. Hee Han reported on the electric quadrupole coupling constant at the Al site as



Figure 3-22 Crystal structure of GaN and AlN (Wurtzite structure). Crystal parameters are also shown.

the coupling constant of ¹²N in AlN precisely enough.

4) LiIO₃ (Lithium Iodate)

The crystal structure of LiIO₃ is shown in Fig. 3-23. This medium is well known as being piezoelectric. The single-crystal specimen of LiIO3 was provided by Dr. R.S. Feigelson. The electric quadrupole coupling constant at the Li site at room temperature had been determined by Sarnatskii [Sa72] using a cw-NMR, |eqQ/h| (7Li in LiIO₃)| = 44 ± 3 kHz. Since the configuration around the Li atom is symmetric in the *a*-*a* plane, the asymmetry factor (η) is zero.

5) LiNbO₃ (Lithium Niobate)

The crystal structure of LiNbO3 is an Ilmenite structure, as shown in Fig. 3-24. A single-crystal specimen of LiNbO3 was obtained from NGK co. [Ng] as a plate. The electric field gradient at the lithium site at room temperature was studied by Peterson and Halstead [Pe67, Ha70] using cw-NMR, |eqQ/h| (⁷Li in LiNbO₃)| = 54.7 ± 0.3 kHz. The asymmetry factor (η) is zero, due to its symmetric configuration around a Li atom in the *a*-*a* plane.

6) Mg (Magnesium)

The crystal structure of magnesium is a hexagonal closest-packed (hcp), as shown in Fig. 3-25. The single-crystal of Mg was purchased from Murakami Engineering [Mu]. The hyperfine interactions of ¹²B in this metal has been studied using the β -NMR method by many authors [Ta77, Ha73, Ki93c]. A. Kitagawa reported on the electric quadrupole coupling

being eqQ/h (²⁷Al in AlN) = 2.2 MHz [Ha88]. We did not use this type sample to determined the quadrupole moment, since we could not measure



| a ₀ α | 5.47 Å 55°43' | rhombohedron |
|--------------------------------------|---------------------|--------------|
| a ₀ ' c ₀ ' | 5.112 Å 13.816 Å | hexagonal |

Figure 3-24 Crystal structure of LiNbO₃ (Ilmenite structure).



 $a_0 = 3.2094 \text{ Å}$ $c_0 = 5.2103 \text{ Å}$

Figure 3-25 Crystal structure of Mg (hexagonal).

constant at room temperature as being $eqQ/h(^{12}B \text{ in Mg}) = -47.0 \pm 0.1$ kHz [Ki90, Ki93c].

3-5 Fourier-Transformed NMR (FT-NMR) 1) Principle of the FT-NMR method

The pulsed and Fourier-Transformed NMR (FT-NMR) method is a popular method for NMR studies [Fu81]. The merit of this method is that it is more effective than the continuous-wave (cw) NMR method. In the FT-NMR method, the spin ensemble over a wide frequency region can be immediately excited by applying a strong, short-pulsed rf field. Information concerning the spin rotations over a wide region can be observed simultaneously.

By applying a strong, short rf pulse to the sample, the spins lie down in the spin rotating frame (Fig. 3-26). After a pulse, the sideways spins precesses around the external magnetic field. The rotation can be monitored by utilizing a surrounding pick up coil as an FID (Free Induction Decay) signal (Fig. 3-27). Since a weak rf field still flows in the coil after the pulse, the differential frequency relative to the applied rf can be observed. The FID signal contains information concerning the rotations of the spin ensemble in the sample. In order to deduce information concerning the spin rotation, the FID signal is Fourier Transformed. Fig. 3-27 shows many examples of FID signals with Fourier-transformed spectra.

2) Typical NMR spectra of highly oriented BN

The BN crystals used in this study were not perfect single crystal, as described above. The distribution of the c-axes that are related to the orientation of the field gradient affects the NMR spectrum. The NMR spectra are calculated based on several angles (α) between the magnetic



High intensity pulsed rf is applied A nuclear spin start precessing effective z axis in the rotating frame fixed to the H_1 field.

Rf pulse is applied till the spin lay in the x-y plane. (90° pulse)



x

After the 90° rf pulse, the spin is precessing around H_0 . This precessing is detected by a pair of pick up coils.

Figure 3-26 Principle of pulsed NMR.

The BK branch and in this spicy were not perfect vingle pressions at described shows. The distribution of the crists that we missel as the striketation of the field gradiest effect the blift of the mine. The fields



Figure 3-27 FID (free induction decay) signal of the spin rotating with frequency ω_L perturbed by the pulsed with frequency ω . If the rotation frequency of the spin is same with the applied rf, FID signal is shown as the exponential decay corresponding with the transverse relaxation time (a). FID signals include the frequency differential from applied rf. (b), (c) field and the crystal direction, in which the *c*-axes are mainly distributed; they are shown in Fig. 3-28. The special characteristic of these spectra is that the shift of the resonance peaks (as seen in the single crystal in Figs. 3-6, 7) cannot be appreciably seen when angle α is changed. The amplitudes of the peaks at $\beta = 90^{\circ}$ ($v = \frac{3\cos^2\beta - 1}{2}v_2 = -\frac{1}{2}v_2$) decrease along with angle α from 90° to 0°. At $\alpha = 0^{\circ}$, the peaks at $\beta = 0^{\circ}$ ($v = \frac{3\cos^2\beta - 1}{2}v_2 = v_2$) can be seen slightly. Comparisons between these results and the experimental ones are given in Chapter 5.





Figure 3-28 Theoretical FT-NMR spectra for ¹¹B in highly oriented BN.

They are resonance spectra between magnetic substates $m = \pm 1/2 \leftrightarrow \pm 3/2$. Note that the frequency of the peak corresponding to β =90° is not changed, but its amplitude is changed.

Chapter 4

EXPERIMENTAL APPARATUS

The β emitters, ⁸Li, ⁸B, ¹²B and ¹²N were produced through nuclear reactions initiated by beams of deuteron and ³He obtained from the 4.75-MV Van de Graaff accelerator at Osaka University. The beam transport system is shown schematically in Fig. 4-1. In order to detect and manipulate spin polarization cleanly, a pulsed beam method was employed; The beam was pulsed by an electric beam deflector/chopper.

The nuclear polarization was measured by detecting β -ray asymmetry from the polarized β emitters. The experimental set up for the production and spin manipulation is shown in Fig. 4-2. The above stated experimental systems as well as the data taking system were supervised by a microcomputer.

This section describes the experimental setup used measuring the electric quadrupole coupling constants of several unstable nuclei: ¹²B in BN, Mg, ¹²N in BN, GaN, AlN, ⁸Li in LiIO₃, LiNbO₃ and ⁸B in Mg.

4-1 Target system

The target for the production of ¹²B and ¹²N was natural boron or enriched ¹⁰B. The chemical forms used here were Li₂O and ⁶LiF for ⁸Li and ⁸B production, respectively. A boron target was prepared by evaporating metallic boron on a Ta backing plate (0.5mm thick) with an electron bombarder. For the evaporation of lithium compounds on a copper backing (1mm thick), a conventional thermal evaporation technique was used. In order to stand for the intense beams of 20µA, the target was placed on a water-cooled target holder (Fig. 4-2). Fig. 4-3 shows the target's dimensions. To reduce the beam intensity for a unit area of the target, the

Beam Slit

Van de Graaff Accelerator



Figure 4-1 Beam transport system.







⁸Li target, respectively.

Figure 4-3 Dimensions of the target. (unit : mm) Backing is the Ta for ¹²B and ¹²N target and the Cu for ⁸B and

target was tilted with a glancing angle of 5° with respect to the incident beam. The energy of the recoil nuclei ejected from the target was spread homogeneously from zero to the maximum energy (Fig. 4-4) in terms of the reaction depth in the target. The recoil angle, defined by a Cu collimator (Fig. 4-2), and the incident beam energy were chosen to optimize the figure of merit, which is defined by the product of the yield of the recoil nuclei and the square of the polarization as $F = n \times P^2$. The experimental conditions of the reaction employed in the present study are summarized in Table 3-1.

The recoil nuclei were then implanted in an implantation medium; a recoil catcher placed in a strong static magnetic field (Table 3-1), which applied parallel to the spin polarization (Fig. 4-2).

Regarding to the materials used for the equipment placed in between the magnetic pole pieces, any magnetic materials were carefully removed . Only non-magnetic materials, such as Cu block and stainless steels, were used.

4-2 β-ray counter system

The β rays were detected by a pair of counter telescopes placed above and below the catcher with respect to the reaction plane (Fig. 4-2). Each telescope consisted of two plastic scintillation counters: an energy sensitive 10mm thick E counter and a thin 2mm thick ΔE counter. The geometry of the counters is shown in Fig. 4-5. A plastic scintillator and a photo tube were connected by a light guide made of acrylates as shown in Fig. 4-6. For the connection an optical cement (admixture of Epikote 828 and Epornite B002 (Petro Chemicals Inc.), the ratio is 2:1) was used. A thin Cu plate (0.5mm) was placed between the two counters in order to stop any low energy β rays that comes from background activities. To avoid any gain shift of the photo tube due to its strong field, the counter system was

0

from the target. emerging out from the target.







Figure 4-5 Detailed geometry around the recoil catcher



Top view of the β -ray detection system.

Figure 4-6 Magnetic shield for the β -ray detection system.

placed away from the electromagnet for the strong field, and was placed in a box made of steel plates. Furthermore each photo tube was shielded by steel and a µ-metal tubes.

Typical time spectra of coincidental β rays are shown in Fig. 4-7. In all cases, contamination of backgrounds were smaller than 1% of total counts.

4-3 Electronic circuit systems for the β -ray detection and spin control

A block diagram of the electronic circuit system is shown in Fig. 4-8. The beam pulsing, the rf for NMR and the β -ray detection systems were supervised by a micro computer (NEC PC - 9801 VX21). The time sequence program of these operations is described in the following section.

1) β -ray detection system

A diagram of the β -ray detection system is shown in Fig. 4-9. The light signal from the plastic scintillator was converted to an electric pulse by the photomultiplier tube (HAMAMATSU R329-01) with a bleeder (HAMAMATSU E934). The timings of the two pulses from the E and ΔE counters were adjusted by pulse-delay modules. To reject any noise signals and/or these small signals from low energy backgrounds, each signal was discriminated by a discriminator (ORTEC Model 924) and an attenuator. Only signals larger than the threshold levels were fed in the coincidence module (ORTEC C314/NL). The coincidence signals were converted to stretched (~5msec) TTL signals by the gate generator (LeCroy Model 222), and were fed into a scalar board (ADTEC AB98-04) mounted in the microcomputer. The scalar data were first read out frequently, then added up in the memory. Finally the data in the memory were transferred to the magnetic disk periodically.



Figure 4-7(a) Typical time spectra of the β counting for ⁸Li and ⁸B.







personal computer (NEC PC-9801 VX21).

Figure 4-8 Block diagram of the computer control. Beam, rf and β -ray detection data taking were supervised by a



2) Rf system for the β -NMR

Diagrams of the rf system for the NMR are shown in Figs. 4-10 ~ 12. The first rf-control system shown in Fig. 4-10 was used for the detection

Four rf systems were used, depending on the type of experiment. As a source of the rf we used either frequency synthesizers (TAKEDA RIKEN TR-3133B, WAVETEK 5135A) or function generators (NF FG-161). of total polarization. The range of a frequency modulation was given by a saw tooth signal obtained from the ramp generator through VCO (Voltage Control Oscillation) produced in a function generator. The calibration between the VCO input voltage and the output frequency is shown in Fig. 4-13.

The next system is used for frequency mapping with a single rf (Figs. 4-11 and 4-12). Both frequency synthesizers were computer controlled through the parallel I/O port. The advantage of the use of these control systems is the capability of fast control compared with any other control systems, e.g., GPIB control.

The last system considered is used for measuring the electric quadrupole coupling frequency (v_Q) , the NNQR method. This is basically the same as the second system. The only difference is the frequency control, this system controls the 5135A instead of the TR-3133B.

We used two kinds of modified drive systems for the NMR rf coil. One was a serial resonance circuit (Fig. 4-14a); the other was a parallel resonance circuit (Fig. 4-14b). The capacity "C" in the figures denotes a variable vacuum capacitor having a wide capacity range of 50 ~ 1500 pF, capable of standing for high voltages of up to 10kV. Since the inductance of the NMR rf coil was about 15µH, the system covered a range of resonance frequencies from 1.1 to 5.8 MHz. The Q values of these circuits were $Q_{ser} \sim 80$ and $Q_{par} \sim 4$; hence, the former was suitable for narrow-



Figure 4-10 Block diagram of the rf control system (2AP mode). Frequency was turned manually. Figure 4-11 Block diagram of the rf control system (2AP, 2rf mode 1). The frequency synthesizer (TAKEDA RIKEN TR3133B) was controlled by the computer.









Figure 4-13 Timing chart of the rf control. Frequency was controlled both digitally and through VCO. It takes about 100µs for the frequency synthesizer to output a stable frequency after the frequency data was set by the computer. The rf gate is applied considering this delay.



Figure 4-14 Rf resonator system

a) Narrow band rf system.

The ferrite core is for impedance matching.

b) Wide band rf system.

The number of turns for the rf input at ferrite core was determined to achieve the enough power and low Q-value.

range mapping with a high rf field H_1 (DQ), while the latter was suitable for wide-range mapping. The Q curve observed for the latter circuit through the test point voltage (Fig. 4-14b) is shown in Fig. 4-15.

An sketch of the rf coil is shown in Fig. 4-16. The rf coil was of the barrel type with a relatively big aperture for the beam. It was made of formal-coated Al wire having a diameter of 0.95mm. Each coil turn was tied with Teflon tapes to three glass rods to keep a shape of the coil. Since the fluorine nucleus in the Teflon tape might produce ²⁰F background through the reaction ${}^{19}F(d, p){}^{20}F$, the coil was hidden from any scattered beam. The parameters of this rf coil are listed in Table 4-1.

Table 4-1 General parameters of rf coil.

Turn number Inductance Intensity at the center of the co

This system can produce an intense rf field of about $H_1 \sim 40$ Oe at the center of the stopper.

3) System control by micro computers A block diagram of the control by a computer is shown in Fig. 4-8. It consists of three blocks. Signals used for the control by the microcomputer NEC PC-9801 VX were TTL logic pulses. The beam-gate-control system utilized three logic signals: "Start", "Stop" and a return signal "Monitor". When the electrostatic beam chopper

| | 20 turns |
|-----|----------------|
| | $L = 15 \mu H$ |
| oil | 8 Oe / A |



Figure 4-15 Q-curve of the parallel resonator system. The very low Q-value is useful for wide range mapping.





Figure 4-16 Overview of the rf coil.

received a "Start" signal, it applied a high voltage (~2.5kV) to the deflector plate with its response time shorter than 100µsec. Due to this high voltage the beam was deflected away from the proper beam line and hits a beam stopper cooled by high-resistive pure water. Upon receiving the "Stop" signal, the beam chopper switched off the high voltage to let the beam pass through. The beam chopper system returned the logic signal "Monitor" which is small and proportional to a negative high voltage.

In order to avoid any saturation of the coincidence and signal discrimination units due to the high counting rate during the beam irradiation time, and any effects caused by the strong rf during the rf time, the signals were locked in front of the units during the beam and rf times. The signals for the beam and rf are shown in Fig. 4-9 as "Beam monitor" and "Rf gate". The power bin gate was controlled by these two signals.

Here, we summarized all of the time sequence programs of the NMR measurements with various rf gates.

The single rf mode for the depolarization is shown in Fig. 4-17. After a beam irradiation time, an rf time and a β -ray counting time followed. The durations of these sections were 25, 5 and 40ms for ¹²B; 15, 4 and 20ms for ¹²N; and finally, 1000, 10 and 1250ms for ⁸B and ⁸Li. If a frequency modulated rf was applied, one sweep time of a saw tooth signal for the VCO, was chosen to be 1ms for ¹²B, ⁸Li and ⁸B, and that for ¹²N 0.8ms. The timing of the control signals and the saw-tooth signal for the VCO are shown in Figure 4-12. The output frequencies of the frequency synthesizer were also controlled by use of the numerical data in the computer. These data were sent to the synthesizer immediately after the beam was initiated in order to produce the frequency as described.

The asymmetry change of the on-resonance cycle from that of the offresonance cycle is defined as follows:

beam

frequency 1

 β -ray counting

rf



$$\begin{split} \Delta &= \frac{R_{on}}{R_{off}} \\ &= \frac{\varepsilon_u}{\varepsilon_d} \frac{1 + AP_{on}}{1 - AP_{on}} / \underbrace{\varepsilon_u}_{\varepsilon_d} \frac{1 + AP_{off}}{1 - AP_{off}} \\ &= \frac{1 + AP}{1 - AP} , \quad \text{for the perfect depolarization (i.e. } P_{on} = 0) \\ &\equiv 1 + 2AP , \quad \text{for } |AP| \ll 1 . \end{split}$$

beam

(4-1)

Here, the subscript "off" indicates the off-resonance cycle (output frequency ~10MHz). The β -ray asymmetry change is -2AP (if $|AP| \ll 1$) for perfect polarization destruction. We thus named this sequence program the "2AP" mode.

Fig. 4-18 shows the time sequence program for measuring of the initial polarization on the nuclei implanted in Pt by means of the AFP technique. In this sequence program, the spin ensemble was inverted by the AFP method. For a perfect cancellation of the effect caused by the fluctuation of the beam position on the target, a count time was further divided in two counting sections. In between the two sections one extra rf time was prepared where the same rf for the beam-count cycle was applied. After rf of the right on-resonance frequency, the spin direction was inverted by the rf. Direction of spin ensemble in each β -ray counting sections are shown in the figure by arrows. The advantage of this sequence program is that the influence from any fluctuation of the incident beam position is excluded, and the figure of merit is improved over that of the depolarization mode by a factor of 4. Neglecting the degree of achievement for the spin inversion and relaxation of the polarization, and assuming no background counting, the NMR effect is described as follows:

β-ray counting

rf

R2

R1

Figure 4-18 Time sequence program of the experiment (8AP mode). Arrows indicate the direction of the spin with perfect inversion by the AFP.

90



$$\Delta' = \frac{R_1}{R_3} \frac{R_4}{R_2}$$

= $\frac{1 + AP_1}{1 - AP_1} \frac{1 - AP_3}{1 + AP_3} \frac{1 + AP_4}{1 - AP_4} \frac{1 - AP_2}{1 + AP_2}$
= $\left(\frac{1 + AP}{1 - AP}\right)^4$, for the perfect inversion
 $\approx 1 + 8AP$, for $|AP| \ll 1$.

(4-2)

The last approximation is valid when $|AP| \ll 1$ is satisfied. An imperfect spin inversion and the effect of relaxation can be seen in the difference between the ratios R1/R3 and R4/R2. We named this sequence program the "8AP" mode.

The last (Fig. 4-19) shows the main sequence program for measuring the electric quadrupole coupling frequency (v_Q) . There is only a slight difference between the time sequence program for the spin I = 1 and that for I = 2, i.e., the number of the rf frequencies to be applied is different. In the following is a description for the case I = 1. Since the resonance peak is split by the coupling frequency (v_Q ; Fig. 3-15b), two kinds of rf's were applied alternately, as shown in figure, in order to destroy the polarization. There was a slight difference between the ¹²B and the ¹²N cases. For ¹²B, rf time follows immediately after the beam end, like in all the other sequence programs. For ¹²N, the rf time begins at the beam time, because the lifetime of ¹²N is too short relative to the sequence. The frequency data are sent immediately after the rf start signal. There is a certain dead time for the frequency synthesizer to give out the frequency, about 40µs for WAVETEK 5135A, and 100µs for TAKEDA RIKEN TR3133B. Therefore rf gates are delayed by 100~200µs from the rf-data signals as shown in the figure. We named this the "NNQR" mode. It is abbreviated as "New Nuclear Quadrupole Resonance".



Figure 4-19 Time sequence program of the experiment (2rf (NNQR) mode).

The frequency operation in the rf gate was different from the 2AP mode. This is shown in the case for the spin I = 1.

4-4 Preparation and treatment of the implantation media

In this experiment, the β -emitting nuclei were implanted in several samples; ⁸Li in LiIO₃ and LiNbO₃, ⁸B in Mg, ¹²B in Mg and BN, and ¹²N in BN, GaN and AlN. Since the implantation depth was shallow less than 1 μ m, it was important to expose their fresh surfaces without damages to vacuum. If the sample was not chemically stable, poor treatments would destroy the crystal structure of the surface. The destruction may reach to a few μ m in depth and the polarization of the implanted nuclei may not be maintained. If the sample was chemically inactive, the crystal surface as it was cleft would be sufficient for the implantation. In this case no additional treatment was necessary.

1) BN

A highly oriented BN crystals were synthesized by the CVD (chemical vapor deposition) method [Su90] at Denka Research Laboratory [De]. A BN crystal is easily cleft with a thin knife, as shown in Fig. 4-20. Since the surface of the cleft one is perpendicular to the *c*-axis. The fresh surface is considered to be free from damages. Therefore no additional treatment was added.

After a few days of implantation using the selected β emitters of 10²/s, the amount of implanted nuclei reached nearly 10⁹, and the sample has a slight brownish color. Colored samples were not used for further implantation experiment.

2) GaN

GaN samples were supplied as single crystals that were grown by the MOCVD (metal organic chemical vapor deposition) method [It85]. It was considered that the surface of the supplied sample was suitable for the

BN sample

20mm

Thin Knife

cleaving the BN sample

Figure 4-20 The BN sample and its cleavage. Highly oriented hBN sample is easily cleft perpendicular to the c-axis by a thin knife.



present implantation experiment. We prepared two types of catcher; one without any treatment and the other with the etching described below. According to the implantation experiments, any difference between them could not be clearly observed. Samples were polished by chemical etching with 85% phosphoric acid (H₃PO₄) for 30 minutes at room temperature. Under this condition, the etching rate was 0.1μ m/min [Si76]. Fig. 4-21 shows the surface of a GaN crystal observed using a metallic microscope having a the magnification × 600. Hexagonal patterns can be clearly seen.

3) AIN

AlN samples were polycrystal. The surface of the AlN sample was etched [Pe76] by use of the etchant which consisted of pure water: glacial acetic acid: nitric acid (HNO₃: 1.40N) = 10 : 10 : 10 by volume. The sample was etched in this etchant for one minute.

4) LiIO3

Since LiIO₃ is deliquescent, the surface of the crystal was obtained by cleaving its surface by a sharp knife in a dry box, and was subsequently placed in the NMR chamber without exposing it to the atmosphere.

5) LiNbO3

LiNbO₃ is sufficiently chemically stable. Since the surface of the sample was supposed to be in a good condition, so that we did not treat the LiNbO₃ samples.

6) Mg

A Mg metallic single crystal was polished by chemical etching with 10% citric acid (C₆H₈O₇) for a few minutes and was rinsed in a 2.8% ammonia



Figure 4-21 Photograph of the surface of the GaN crystal. The surface of the GaN crystal grown by MOCVD on a Al_2O_3 plate. (600 magnifications) : 1 division = 2.5 µm. The hexagonal structure can be seen clearly at the surface. solution under ultrasonic agitation for a few seconds. The surface was then dried by blowing its surface with a strong flow of dry N2 gas.

Chapter 5

EXPERIMENTAL RESULTS

5-1 Quadrupole moment of ¹²B 1) β -NMR detection of ¹²B in BN

The quadrupole coupling constant (eqQ/h) of stable ¹¹B at the boron site of BN was reported by Connor [Co90] and Silver [Si60], who used the conventional NMR detection of the stable isotopes. The quadrupole moment of ¹²B had been reported by Minamisono et al. [Mi78]. With these values, the coupling constant (eqQ/h) for ¹²B was given with the relative error of ~10%.

As a first step, the polarization maintained during the implantation was measured for ¹²B in a BN crystal. An rf oscillating field (H_1) with a very wide frequency modulation (FM; 1 MHz), which covered all of the resonances of ${}^{12}B$ in BN, was applied. The observed polarization (P) was about 2.5%. About 36 Oe of H_1 was sufficiently strong for a perfect destruction of the polarization. Two thirds of the polarization produced in the nuclear reaction was destroyed during the implantation.

In the next step, the resonance frequency of the double quantum transition ($v_{DO}: m = 1 \leftrightarrow -1$) was observed. A double quantum transition requires an even stronger field (H_1). H_1 was 46 Oe and FM was ± 20 kHz. A rough mapping result is shown in Fig. 5-1. The observed polarization change was consistent with that observed in the previous step (single quantum transition: SQ). Mapping of the frequency was then carried out with a monochromatic (no FM, and $H_1 = 28$ Oe) rf. A typical observed spectrum obtained at $H_0 = 5$ kOe and T = 300K is shown in Fig. 5-2. The half width at half maximum (HWHM) of the observed spectrum was



Figure 5-1 Detection of double quantum transition (DQ) of ^{12}B in BN. The double quantum transition frequency was roughly measured by the β -NMR method. The horizontal bar expresses FM. The highly oriented axis of BN was perpendicular to the external field.



Figure 5-2 Detection of DQ transition of ¹²B in BN with a monochromatic rf.
The double quantum transition frequency was measured precisely.
The highly oriented axis of BN was perpendicular to the external field. The solid curve is the best theoretical fit to the data.



obtained by fitting a theoretical spectral function to the data. The experimental results are shown in Table 5-1.

Table 5-1 Fitting result of the double quantum transition of ¹²B in BN at $H_0 =$ 5kOe and T = 300K.

| Function type | Center frequency (kHz) | Width (kHz) | χ^2 |
|---------------|---------------------------|------------------|----------|
| Lorentzian | 3844.91 ± 0.77 | 10.58 ± 1.17 | 0.82 |
| Gaussian | 3844.89 ± 0.97 | 14.48 ± 1.18 | 1.11 |

The observed v_{DQ} was utilized so as to make a frequency table of two SQ transitions as a function of eqQ/h that are necessary for NNQR detection. The obtained SQ resonance frequencies and Larmor frequency are shown as a function of eqQ/h in Fig. 5-3 for the observed v_{DQ} . Note that the estimated Larmor frequency varies with eqQ/h since the *c*-axis is placed vertical to the externally applied strong magnetic field.

Finally, a typical spectrum obtained at $H_0 = 5$ kOe and T = 300K was observed by the NNQR method, as shown in Fig. 5-4. The horizontal axis is the quadrupole coupling frequency (v_Q ; = 3/4 eqQ/h for $\beta = 90^\circ$) and the vertical axis the β -ray asymmetry change. The angle between the external field and the main *c*-axis of BN was $\beta = 90^\circ$. At higher frequencies, the resonance curve is consistent with the predicted shape for the substitutional boron site. The asymmetry parameter of the electric field gradient was expected to be $\eta = 0$ based on the symmetry of the BN crystal structure in the *a*-*a* plane. The intensity of the applied rf field was 3 Oe. FM was ± 40 kHz. At lower frequencies, a small lump can be seen, which is considered to come from the substitutional nitrogen site. The spin of the nucleus



Figure 5-3 Two single quantum (SQ) frequencies and the Larmor frequency v_L as a function of the coupling constant (eqQ/h). The rf frequency table for the control of the frequency synthesizer was made from this data.



Figure 5-4 Typical NNQR spectrum for ¹²B in BN. The quadrupole coupling constant of ¹²B in BN was detected by use of the NNQR method. The holding external magnetic field was $H_0 = 5$ kOe. The highly oriented axis was perpendicular to the H_0 . The solid curve is the best theoretical fit to the data. settled in an interstitial site is rapidly depolarized through the paramagnetic relaxation mechanism before the β -ray counting time is started. The width of the spectrum mainly results from the FM. Other causes are the dipolar broadening, rf intensity, and fluctuation of the electric field gradient due to the implantation process. These effects were considered in the line-shape fitting. The effect from the deviation of the *c*-axes was rather small because of the experimental condition ($\alpha = 90^\circ$; mainly, $\beta = 90^\circ$; see Chapter 3-5-2). The obtained coupling constant is $|eqQ/h|(^{12}B \text{ in BN})| = 944 \pm 17 \text{ kHz}.$

Measurement of the electric field gradient by detecting FT-NMR for ¹¹B in BN

As mentioned in the previous section, Silever reported on the eqQ/h of ¹¹B ($I^{\pi} = 3/2^{-}$) in BN at room temperature, $|eqQ/h(^{11}B \text{ in BN})| = 2.96 \pm 0.1 \text{ MHz}$ [Si60]. Its accuracy was poor because they used a polycrystal sample. Connor reported on the eqQ/h of ¹¹B in BN detected at liquid-He temperature, $|eqQ/h(^{11}B \text{ in BN})| = 2934 \pm 4 \text{ kHz}$ at 4.2K [Co90]. In the present experiment, the coupling constant of ¹²B in BN was measured at room temperature. Therefore eqQ/h (¹¹B in BN) value at room temperature must be measured in order to avoid any uncertainty that may come from the temperature dependence of eqQ value. We measured the coupling frequency by means of the pulsed Fourier-transformed NMR method (FT-NMR).

The samples were cut and stacked for the FT-NMR method as shown in Fig. 5-5. The NMR spectra were observed at several angles (α) between the main *c*-axis of the BN sample and the external field. As mentioned in the preceding section (Chapter 3-4-1), the *c*-axes of the present BN crystal were distributed around the main direction. The NMR spectrum thus showed a characteristic dependence of the angle relative on the external magnetic field. Figs. 5-6(a)~(c) show the NMR spectra for several angles





Figure 5-5 Stacking of BN samples for a pulsed NMR study.



Figure 5-6 FT-NMR spectra of ¹¹B in BN at (a) $\alpha = 80^{\circ}$, (b) $\alpha = 60^{\circ}$ and (c) $\alpha = 0^{\circ}$. The external field was $H_0 = 47$ kOe. Horizontal axis shows the frequency deviation from the applied rf frequency f. Two resonance peaks are shown. The right peak is for the transition between $1/2 \leftrightarrow -1/2$. The left one is for $\pm 1/2 \leftrightarrow \pm 3/2$. The frequencies of the peaks show the main component of the spectrum is correspond β = 90° at α =80°. The frequency of the peak is not change but the amplitude decreased when the angle α is decreased. At $\alpha = 0^{\circ}$ (c), a peak for $\beta = 0^{\circ}$ can be seen but the amplitude is small. It is because of the distribution of the c-axes in the BN sample.

at an external magnetic field of $H_0 = 47$ kOe. Note that the resonance peak at $\beta = 90^{\circ}$ is not moved as a function of angle α , and that the amplitude decreases as α is decreased from 90° to 0°. This is in good agreement with a prediction based on the c-axes distribution of the BN sample (Chapter 3-5-2).

The electric quadrupole coupling constant was derived as leqQ/h (¹¹B in BN)I = 2902 ± 12 kHz based on the data obtained at β = 90°. This value is in good agreement with the one obtained by Nesbet, $leqQ/hl = 2960 \pm 100$ kHz.

3) Temperature dependence of the quadrupole interaction of ¹¹B in BN

The present value of the electric quadrupole coupling constant of ¹¹B in BN is in good agreement with the previous one, which was mentioned in the preceding section. Compared with Connor's data, |eqQ/h| (11B in BN)| = 2934 ± 4 kHz at 4.2K [Co90], the temperature dependence of the coupling constant can be deduced as $\Delta eqQ/h = \{eqQ/h(at 4K) - eqQ/h(at 300K)\}/$ eqQ/h (at 300K) = 1.1 ± 0.4 %.

4) Electric quadrupole moment of ¹²B

Using the known electric quadrupole moment of ¹¹B, the electric field gradient at the substitutional B site for the 12B nucleus can be derived as given in Table 5-2. The quadrupole moment $Q(^{11}B) = +40.65 \pm 0.26$ mb, as reported by Nesbet [Ne70] is in good agreement with the improved value $Q(^{11}B) = +40.59 \pm 0.10$ mb for which Sundholm et al. [Su91] calculated the field gradient by use of the improved electronic structure. Since these values agree with each other, we adopted the latter value for the present standard. Considering this value $Q(^{11}B)$ and the obtained coupling constant eqQ of ¹¹B in BN, the electric field gradient at ¹¹B

 $|Q(^{12}B)| = 13.4 \pm 1.4 \text{ mb}$ [Mi78]. We do not need to consider the same for both the ¹¹B and ¹²B in the BN samples.

Table 5-2

Electric quadrupole moment of ¹²B.

| Nucleus | Implantation media | leqQ/hl (kHz) | Method | Temperature (K) | e Ref. |
|---------|--------------------|------------------|---|--------------------|---------|
| 12B | BN | 944 ± 17 | NNQR | ~300 | present |
| | | | (β-NMR) | | |
| 11B | BN | 2902 ± 12 | FT-NMR | ~300 | present |
| | | 2960 ± 100 | cw-NMR | ~300 | [Si60] |
| | | 2934 ± 4 | NQR | 4.2 | [Co90] |
| | | | $Q(^{11}B) = +40.59 \pm 0.10 \text{ mb}$ $ Q(^{12}B) = 13.20 \pm 0.25 \text{ mb}$ | | mb |
| | | | | | mb |
| 12B | ZrB ₂ | 38.7 ± 1.1 | β-NMR | ~300 | [Mi78] |
| 11B | ZrB ₂ | 118 ± 10 | cw-NMR | ~300 | [Si60] |
| | | | $ Q(^{12}B) =$ | 13.4 ± 1.4 mb | |

| Nucleus | Implantation media | leqQ/hl (kHz) | Method | Temperature (K) | e Ref. |
|-----------------|--------------------|------------------|---|--------------------|---------|
| 12B | BN | 944 ± 17 | NNQR | ~300 | present |
| | | | (β-NMR) | | |
| 11B | BN | 2902 ± 12 | FT-NMR | ~300 | present |
| | | 2960 ± 100 | cw-NMR | ~300 | [Si60] |
| | | 2934 ± 4 | NQR | 4.2 | [Co90] |
| | | | $Q(^{11}\text{B}) = +40.59 \pm 0.10 \text{ mb}$ | | mb |
| | | | $ Q(^{12}B) = 13.20 \pm 0.25 \text{ m}^{2}$ | | nb |
| 12 _B | ZrB ₂ | 38.7 ± 1.1 | β-NMR | ~300 | [Mi78] |
| 11B | ZrB ₂ | 118 ± 10 | cw-NMR | ~300 | [Si60] |
| | COLUMN T | | $ Q(^{12}B) =$ | 13.4 ± 1.4 mb | |

nucleus was deduced to be $|q|^{(11B)}$ in BN $| = (4.7 \pm 0.2) \times 10^{20} \text{ V/m}^2$. From this value and the observed coupling constant of ¹²B in BN, the electric quadrupole moment of ¹²B was deduced to be $|Q(^{12}B)| = 13.20 \pm 0.25$ mb. This value is consistent with the previous value by Minamisono et al., Sternheimer polarization effect, because the theoretical calculation is based on the first principle method. Moreover the electronic structures are the

5-2 Quadrupole moment of ¹²N

There was no helpful information available concerning the quadrupole moment of ¹²N and the electric field gradient of the samples. The experiment therefore rather complicated compared with the ¹²B case.

1) β-ray detection of ¹²N in BN, GaN, and AlN

(i) Polarization maintained in crystals

As the first step, the maintained polarization of ¹²N in several materials was studied using a widely frequency-modulated oscillating field. Fig. 5-7 shows the field (H_1) strength dependence of the β -ray asymmetry change in BN and GaN, respectively. It is very interesting that the maintained polarizations in these media were almost equal. The initial polarization of ¹²N was measured by implanting ¹²N in Pt metal, which is a good medium for preservation. Since $AP_0 = 17\%$, about 2/5 of the initial polarization was maintained in these nitride samples.

To account for these results, the external magnetic field dependence of the B-ray asymmetry measured for BN and GaN. Mylar and Pt were also used to measure the asymmetry for normalization. In the Mylar, polarization was completely destroyed. The results are shown in Fig. 5-8(a) (for BN) and (b) (for GaN). Since the efficiency of the β -ray counters, unfortunately, depends on the external field slightly, normalization of the dependence was as follows: (1) In each magnetic field, the Mylar result was considered as normalization. (2) At zero magnetic field, the polarization was expected to be perfectly destroyed in all samples. The differences among the results of the up-down ratio (U/D) at zero field for different media were due to the different settings and the thicknesses of the samples. To reduce this geometrical asymmetry, the ratios at the zero field of each medium were normalized using one of the Mylar data. (3) The maintained polarization was measured by detecting the β -NMR of each



Figure 5-7 H_1 dependence of the NMR effect for ¹²N in (a) BN and (b) GaN. The crystal c-axis is perpendicular to the external field.



Figure 5-8 H_0 dependence of the asymmetry of the β -ray counting for ¹²N.

Including the data at liquid N2 temperature for BN. The effect on the β -ray counter system by the external field can be seen from the up/down ratio for Mylar and Pt metal.

nuclide in Pt at 5 kOe or 7 kOe. Based on these results, the geometrical asymmetry caused by the catcher and the detection systems can be estimated. However they are not in agreement with that deduced from (1) and (2) for GaN. This may be because the setting of the samples depends on the external field. In order to normalize this influence, the up/down ratio for the P = 0 was defined by the result obtained from the NMR in Pt. With this definition, the H_0 dependence of the maintained polarization was obtained, as shown in Fig. 5-9 for GaN.

For BN, because there was no data available, step (3) was not performed. The maintained polarization was deduced from step (1) and (2). The observed polarization (NMR) was consistent with this estimation within the experimental error. This means that all available resonance could be identified completely detecting by β -NMR. For GaN, the maintained polarizations deduced from β -NMR and this estimation were also in agreement. This means that all of the polarization was spread within the range of the Larmor frequency ± 100 kHz.

By using this method, however, the amount of polarization could not be determined precisely, because of the fluctuation in the beam condition (e.g., beam position on the target). For example, such fluctuation can be seen in the ratios with the same experimental condition in Fig. 5-8. Thus, the experimental precision of this estimation should not be taken too seriously.

(ii) Temperature dependence of the β -NMR

Fig. 5-10 shows the temperature dependence of the maintained polarization by use of the NMR detection of ¹²N in BN. The observed polarization decreased as the temperature decrease. At the same time, although the external field dependence of the β -ray asymmetry was measured, no significant dependence was observed within the present error







Figure 5-10 Temperature dependence of the NMR effect for ¹²N in BN.

The maintained polarization detected by NMR decreases at low temperatures. The horizontal bars show the temperature region.

Temperature (K)

(Fig. 5-8). It is not clear why the NMR effect partially vanished at lower temperatures. One of the reasons that there is an interstitial metastable site where at a lower temperature, majority sat without moving to the substitutional site. At that site, although the polarization was preserved, the electric field gradient was too large to be observed by the NMR method.

(iii) Double quantum transition

Double quantum (DQ) transitions between m = 1 and -1 in BN, GaN and AIN were measured for the succeeding NNQR measurement. At first, the H_1 dependences of the DQ effect were measured, as shown in Fig. 5-11, for each media. The frequency of applied the rf was 1742 ± 5 kHz. The width of the FM fully covered the DQ resonance width caused by the dynamic dipolar fields. The field $H_1 \sim 5$ Oe was sufficient to destroy the polarization through the DQ transition. In the next step, the NMR spectra of the DQ transition were observed (Figs. 5-12 - 14) for each medium. The resonance frequency consists the Larmor frequency and the higher order shift due to the electric quadrupole interaction. The condition of the applied rf was $H_1 = 9$ Oe for BN and 5 Oe for GaN and FM = ± 1 kHz. The spectra were analyzed by fitting them with a resonance function which was based on Lorentzian or Gaussian line shape function. The experimental results are listed in Table 5-3. The widths of these resonances are consistent with the one given by the dipolar broadening and the rf intensity.



B-ray asymmetry change (%)

Figure 5-11 H_1 dependence of the double quantum (DQ) transition for ¹²N in (a) BN, (b) GaN and (c) AlN. $f = 1742 \pm 5$ kHz, $H_0 = 5$ kOe. The crystal highly oriented axis is perpendicular to the external field for BN. The crystal c-axis is perpendicular to the external field for GaN. AlN sample was polycrystal.







Figure 5-13 Detection of DQ resonance of ¹²N in GaN. The solid curve is the best theoretical fit to the data.



Figure 5-14 Detection of DQ resonance of ¹²N in AlN. The AlN sample was the polycrystalline. The solid curve is the best theoretical fit to the data.

Table 5-3 Experimental results of the double quantum transition of ¹²N in BN, GaN and AlN.

| Implantation media | Center frequency (kHz) | Width (kHz) | χ ² |
|-----------------------|---------------------------|-----------------|----------------|
| | Lorentzian t | уре | |
| BN | 1742.00 ± 0.33 | 3.56 ± 0.56 | 0.63 |
| GaN | 1742.20 ± 0.15 | 1.54 ± 0.23 | 1.99 |
| AIN | 1742.41 ± 0.32 | 3.25 ± 0.50 | 0.55 |
| | Gaussian typ | e | |
| BN | 1742.19 ± 0.34 | 4.10 ± 0.45 | 0.79 |
| GaN | 1742.40 ± 0.19 | 2.18 ± 0.25 | 2.51 |
| AIN | 1742.56 ± 0.34 | 3.99 ± 0.34 | 0.93 |

(iv) β -NMR detection of 12N

Finally, the electric quadrupole coupling frequency (v_0) was measured. Using the experimental DQ resonance frequency, two rf frequencies corresponding to a coupling frequency v_Q were calculated. The rf intensity (H_1) and FM of the rf were properly tuned, since we needed to avoid any DQ resonance near to the Larmor frequency ($v_Q = 0$). The DQ transition can be suppressed if the rf power is small enough. However, H_1 can not be too small to observe the eqQ spectrum efficiently, since an rf with wide FM must be use because the NMR line is broadened by some reasons and H_1 must be properly increased. The use of frequency-modulated rf is to integrate the NMR effect spread in the rf range, and the NMR detection of the quadrupole effect easier. However an FM that is too wide causes the spectrum to be distorted, especially for the inner side of peaks, i.e., a
resonance peak is widened by the FM toward the inner side. Figs. 5-15-17 show the final results for the v_0 measurements.

a. BN

Fig. 5-15 shows the NNQR spectrum for ¹²N in BN. The experimental condition was that FM width was $\pm 1 \text{ kHz}$, $H_1 \sim 2.8 \text{ Oe at } H_0 = 5 \text{ kOe and } T$ = 300K. Note that the width of FM (Δf) is twice as much when using v_0 scale, i.e., $\Delta v_0 = 2\Delta f$. The horizontal bar in the figure shows the FM range of an applied rf. Fitting functions based on the Gaussian shape was used for a χ^2 analysis of the spectrum. The experimental results are listed in Table 5-4. According to the study of ¹²B in BN, one another component that comes from ¹²N located in substitutional boron site is suggested. Based on a peak search, however, in the region $v_0 \le 2$ MHz, no apparent such peak from the possible component was found. It was therefore concluded that this component is located either far outside of the searched range that comes from a very large electric field gradient, or too close to that of the substitutional site. Furthermore, since the observed NMR effect is almost 80% of the maintained polarization, we concluded that the present peak is that resulting from ¹²N in the nitrogen site.

b. GaN

Fig. 5-16 shows the spectrum for ¹²N in GaN. It is expected that the site where ¹²N is located with its polarization maintained is the only nitrogen substitutional site. Since the Ga atom is much heavier than N, it is unlikely for an implanted ¹²N to settle in a Ga substitutional site.

The condition for the rf fields was $FM = \pm 5 \text{ kHz}$ and $H_1 = 0.8 \text{ Oe}$ at H_0 = 5kOe and T = 300K. The analysis was the same as for ¹²N in BN. The experimental results are listed in Table 5-4. It was found that the field gradient was about one half that in BN.



Figure 5-15 Typical NNQR spectrum of ¹²N in BN. The quadrupole coupling constant of ¹²N in BN was detected by use of the NNQR method. The solid curve is the theoretical spectrum best fit to the data.

the test instantia for the top measurements.



Figure 5-16 Typical NNQR spectrum of ¹²N in GaN. The solid curve is the theoretical spectrum best fit to the data.



Figure 5-17 Typical NNQR spectrum of ¹²N in AlN. The quadrupole coupling constant of ¹²N in AlN was detected by use of the NNQR method. A polycrystal pattern is expected. Resonance peaks at $\beta = 90^{\circ}$ can not be seen clearly due to the broadening. The width of the spectrum is accounted for by the FM width of the applied rf field and a reasonable spread of the field gradient. Since the rf intensity (*H*₁) is equal to about 1 kHz, and the dipolar broadening at the nitrogen site is 1 kHz, both are negligibly small, the width is considered to be due to the spread in the field gradients. There are two origins of the inherent spread in the field gradient, i.e., one results from radiation damage produced in the implantation process; the other results from vacancies which are in the crystal. The former origins are observed in many cases, e.g., 17F in MgF₂ [Mi84] and ⁴¹Sc in TiO₂ [Mi93b]. The latter, i.e., vacancies, are unavoidable in the process of the crystal synthesis by the MOCVD method. In addition to the nitrogen vacancies, even impurities such as oxygen ions, may be introduced by this process.

Table 5-4

Experimental results of the quadrupole coupling frequency (v_Q) of ¹²N in BN and GaN.

| Implantation media | $v_Q \qquad (kHz) \\ = \frac{3}{4} \frac{eqQ}{h}$ | Width (kHz) (HWHM) | χ ² |
|-----------------------|---|----------------------------------|----------------|
| - | Lorentzian | | |
| BN GaN | 43.3 ± 2.4 20.0 ± 1.7 | 20.7 ± 4.7 16.1 ± 3.8 | 0.70 1.06 |
| | Gaussian | | |
| BN GaN | 42.6 ± 2.4 20.6 ± 1.5 | 23.7 ± 3.7 18.4 ± 2.1 | 0.68 1.15 |

c. AIN

Fig. 5-17 shows the NNQR detection of ¹²N in AlN. The condition was $H_1 = 1.5$ Oe and FM = ± 1 kHz. The spectrum did not show an explicit peak for *eqQ*. Since it was too difficult to precisely analyze this spectrum, so we did not use this data for extracting the electric quadrupole moment. However, the rough data for the electric quadrupole coupling frequency was deduced as $v_Q(^{12}N \text{ in AlN}) = 15$ kHz.

2) Measurement of the electric field gradients by detecting the FT-NMR of ¹⁴N in BN, GaN

The electric field gradients at the nitrogen site in BN and GaN were measured by pulsed FT-NMR on ¹⁴N ($I^{\pi} = 1^+$). BN samples were cut out from the very sample used for the β -NMR. A GaN (powder) sample was obtained from KOJUNDO-KAGAKU. The purity of the GaN sample was 4N grade. The observed spectra that were the FT-NMR spectra are shown in Figs. 5-18~19. The difference of these data in Fig. 5-18 is the choice of the initial sampling point for the Fourier transformation. Since the FID signals just after the stop of an rf pulse is often deformed by the rf pulse or that of the coil set up mismatching, so the derived Fourier-transformed spectrum is very much distorted. To avoid this distortion, initial point of the sampling is delayed after the pulse. However, note that the shape of the true component was also distorted as the sampling time is delayed. The effect of the choice of the initial point can be seen in the spectra. However the distances of frequencies of the relevant peaks are not moved appreciably.

From these spectra, one recognize a broad distortion near the Larmor frequency, i.e., between the two quadrupole peaks. This distortion is due to a mismatching of the rf conditions [He84], The distortion affects the frequencies of the satellite peaks. Here, it was considered in the analyses as



Figure 5-18 Typical FT-NMR spectra of ¹⁴N in BN. Sampling start point dependence of the FT-NMR spectra. The distortion near center was caused by the mismatching of the rf. It depends on the sampling start point for Fourier-transformation. The peak for the angle β =90° can be seen clearly. The highly oriented axis was perpendicular to the external field H_0 . Applied external field was H_0 .= 47 kOe. Applied rf frequency was f = 14456.5kHz



Figure 5-19 Typical FT-NMR spectrum of ¹⁴N in GaN. The distortion at center was caused by the mismatching of the rf.



Frequency deviation (kHz)

being a simple Gaussian without any fine structures. Thus, these spectra were analyzed by fitting three Gaussian functions. The results are shown in Table 5-5. In the case of ¹⁴N in GaN, we supposed that the width of spectrum was due to dipolar broadening as well as the exponential decay of the FID signal [Fu80].

Table 5-5

Results of the FT-NMR spectra on ¹⁴N in BN and GaN.

| Media | leqQ/hl (kHz) |
|-------|-----------------------------|
| BN | $110.7 \pm 4.1 \text{ kHz}$ |
| GaN | $49 \pm 15 \text{ kHz}$ |

3) Electric quadrupole moment of ^{12}N

As in the case of ¹²B, the electric field gradient for ¹²N at the nitrogen site was deduced based on the observed *eqQ/h* for ¹⁴N in BN and GaN combined with the known electric quadrupole moment of ¹⁴N. The electric quadrupole moment of ¹⁴N was recently reported by many authors. It had been difficult to accurately calculate the electric field gradient for a nitrogen molecule because of its possible complex molecular configurations. However, Schimacher et al. observed the hyperfine splitting of the excited nitrogen atom by using the IBSIGI (ion beam surface interaction grazing incidence) method and deduced the quadrupole moment of ¹⁴N as $Q(^{14}N) = +20.0 \pm 0.2$ mb [Sc92]. Using this value, the electric field gradient at the nitrogen site in BN and GaN were deduced as $|q(N \text{ in BN})| = (2.29 \pm 0.09) \times 10^{20} \text{ V/m}^2$ and $|q(N \text{ in GaN})| = (1.0 \pm 0.3) \times 10^{20} \text{ V/m}^2$. Then, the quadrupole moment of ¹²N was deduced as $|Q(^{12}N)| = 10.3 \pm 0.7$ mb from BN data and $|Q(^{12}N)| = 9.2 \pm 3.1$ mb from GaN. These values are in good agreement with each other within the experimental concerning errors. This consistency also assures us of the validity of the speculation that the observed resonance peak for ¹²N in BN came from ¹²N in the nitrogen substitutional site. The average of these values is adopted as the final result, $|Q(^{12}N)| = 10.3 \pm 0.7$ mb.

5-3 Quadrupole moment of ⁸Li 1) β-NMR detection of ⁸Li

At first, in order to obtained Larmor frequencies for ⁸Li in LiIO₃ and LiNbO₃, the resonance frequencies at the magic angle (β_M) were observed. At the magic angle, all of the transition frequencies are coincident. For ⁸Li in LiIO₃ and LiNbO₃, they are coincident at the Larmor frequency. At the magic angle, all transition frequencies are equal to the Larmor frequency in the present experimental condition. Typical β -NMR spectra are shown in Fig. 5-20 for LiIO₃ and 5-21 for LiNbO₃, respectively. The experimental results are shown in Table 5-6. The external magnetic field was $H_0 = 4$ kOe at T = 300K, and the intensity of monochromatic rf's was 0.53 Oe.

Table 5-6

Experimental results of β -NMR LiNbO₃. The external field was

| Implantation media | Center frequency (kHz) | Width (kHz) | χ^2 | |
|-----------------------|---------------------------|-----------------|----------|--|
| Lorentzian ty | pe | | | |
| LiIO ₃ | 2521.85 ± 0.06 | 0.64 ± 0.09 | 0.54 | |
| LiNbO3 | 2521.69 ± 0.10 | 1.93 ± 0.16 | 1.00 | |
| Gaussian type | | | | |
| LiIO ₃ | 2521.85 ± 0.06 | 0.64 ± 0.09 | 0.54 | |
| LiNbO3 | 2521.69 ± 0.10 | 1.93 ± 0.16 | 1.00 | |

| at the | magic | angle | for | 8Li | in | LiIO ₃ | and |
|----------|--------|-------|-----|-----|----|-------------------|-----|
| $H_0 = $ | 4 kOe. | | | | | | |



Frequency (kHz)

Figure 5-20 Typical β -NMR spectrum of ⁸Li in LiIO₃. The angle between the crystal *c*-axis and the external field was magic angle (54.7°).



Figure 5-21 Typical β -NMR spectrum of ⁸Li in LiNbO₃. The angle between the crystal *c*-axis and the external field was magic angle (54.7°).

Frequency (kHz)

Finally, the electric quadrupole coupling frequency (v_0) was measured at room temperature. Typical NNQR spectra for ⁸Li in LiIO₃ and LiNbO₃ are shown in Figs. 5-22 and 5-23, respectively. The external field was $H_0 =$ 4 kOe. The intensity of the applied rf's was 0.9 Oe. The rf was monochromatic for LiIO₃, and was modulated as ± 1 kHz for LiNbO₃. The crystal c-axis, i.e., the direction of the electric field gradient, was parallel to the external field (H_0) . The solid curves are the theoretical spectra which are best fit to the data. In the analysis, the spread of the field gradient $(\Delta q/q)$, and the contribution from the DQ transitions were taken into account. A spread of $\Delta q/q = 5\%$ was obtained from the fits, which is consistent with the previous one [Mi75]. These results are listed in Table 5-7.

Table 5-7

Experimental results of the quadrupole coupling frequency v_Q of ⁸Li in LiIO3 and LiNbO3.

| Implantation media | $\frac{v_Q}{=\frac{1}{4}\frac{eqQ}{h}}$ | eqQ/h(kHz) | $\Delta q/q$ (kHz) (HWHM) | χ ² | |
|-----------------------|---|-----------------|------------------------------|----------------|--|
| LiIO ₃ | 7.39 ± 0.27 | 29.6±1.1 | 0.96±0.16 | 0.75 | |
| LiNbO3 | 11.18 ± 0.21 | 44.6 ± 0.88 | 2.14 ± 0.09 | 0.56 | |

The coupling constants were determined to be $|eqQ/h| (^{8}Li \text{ in } LiIO_{3})| =$ 29.6 ± 1.1 kHz and $|eqQ/h| (^{8}Li \text{ in LiNbO}_{3})| = 44.68 \pm 0.88$ kHz. They are in good agreement with the previous values [Mi75, Ar88].



Figure 5-22 Typical NNQR spectrum of ⁸Li in LiIO₃. The quadrupole coupling constant of ⁸Li in LiIO₃ was detected by use of the NNQR method. The solid curve is the theoretical spectrum best fit to the data.



Figure 5-23 Typical NNQR spectrum of ⁸Li in LiNbO₃. The quadrupole coupling constant of ⁸Li in LiNbO₃ was detected by use of the NNQR method. The solid curve is the theoretical spectrum best fit to the data.

NMR of 7Li in LiIO3 and LiNbO3

The field gradients at the Li site in the crystal were measured by detecting FT-NMR on the stable isotope ⁷Li ($I^{\pi} = 3/2^{-}$). The typical FT-NMR spectra are shown in Figs. 5-24 and 5-25 for LiIO3 and LiNbO3, respectively. They were observed in an external magnetic field $H_0 =$ 47 kOe at room temperature. The spectrum for LiIO3 was very disturbed by the piezo-electric character of the LiIO3 crystal. This distortion, i.e., the asymmetry of three peaks and a broad pit near to the center, prevented us from a precise determination of the center frequencies. Fortunately, however, each of the three major lines showed a clear micro structure that result from a dipolar interaction of ⁸Li with the surrounding ⁷Li nuclear moments. Based on the relative intensities of the peaks from the dipolar split, the center of each transition was identified. Thus, the determined frequency spacings were plotted as a function of the angle of the crystal caxis relative to the external magnetic field (Fig. 5-26). The solid and broken lines are the theoretical curves which best fit the data. The asymmetry factor (η) of the electric field gradient was assumed to be zero, because of the crystal symmetry. The quadrupole coupling constants were obtained as $|eqQ/h(^7\text{Li in LiIO}_3)| = 36.4 \pm 0.5 \text{ kHz and } |eqQ/h(^7\text{Li in })|$ $LiNbO_3| = 53.3 \pm 0.5$ kHz. It was found that the previously reported $|eqQ/h(^7\text{Li in LiIO}_3)| = 44 \pm 3 \text{ kHz} [Sa72]$ is in error because the piezoelectricity may not have been taken into account.

3) Electric quadrupole moment of ⁸Li

The quadrupole moments of ⁷Li has been reported by many authors recently [Vo91, Su85], and the results are all consistent. Here, we adopted the result based on Coulomb excitation by Völk, $Q(^{7}Li) = +40.0 \pm 0.6$ mb.

2) Measurement of the electric field gradients by detecting the FT-



Figure 5-24 Typical FT-NMR spectrum of 7 Li in LiIO₃. All transition peaks are shown. The distortion was occurred due to the piezo-electricity character of LiIO₃. The horizontal axis shows the

piezo-electricity character of $LiIO_3$. The horizontal axis shows the deviation from the applied rf frequency.

To manufacture demonstrate of "EI has here reported by many address The quantupole moments of "EI has here reported by many address meaning (VoP1, SoR5), and the revice are all considered blers, we adopted a second based on Coule a bracit total by Volk, QCT23 & 100.000 0.00 mb



Figure 5-25 Typical FT-NMR spectrum of 7 Li in LiNbO₃. All transition peaks are shown. The horizontal axis shows the deviation from the applied rf frequency.

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Frequency deviation (kHz)



Rotation angle between q and H_0 (degree)

Figure 5-26 FT-NMR signal of ⁷Li in LiIO₃ and LiNbO₃ as a function of the orientation of the crystal c-axis relative to H_0 . The solid and broken curves are the best theoretical fit to the data. Using this quadrupole moment, the electric field gradients at the Li site were obtained (Table 5-8).

Table 5-8 present quadrupole moment values.

| Sample | lql (V/m ²) | IQ(⁸ Li)I (mb) |
|-------------------|--------------------------------|----------------------------|
| LiIO ₃ | $(3.8 \pm 0.1) \times 10^{19}$ | 32.1 ± 0.8 |
| LiNbO3 | $(5.5 \pm 0.1) \times 10^{19}$ | 33.5±0.9 |

Then, the electric quadrupole moment of the ⁸Li was deduced to be average of these values, we found $|Q(^{8}Li)| = 32.7 \pm 0.6$ mb.

5-4 Quadrupole moment of ⁸B Hyperfine interactions of both ⁸B and ¹²B in a solid are expected to be similar because of the same atomic structure. The Knight shift and electric field gradient at the boron site in Mg were thus the same for both ⁸B and ¹²B. We determined these values for ⁸B from a measurement of ¹²B in

Mg.

by detecting β -NMR of ¹²B in Mg

Observed electric field gradients at Li site in LiIO3 and LiNbO3 and the

 $|Q(^{8}Li)| = 32.1 \pm 0.8$ mb and 33.5 ± 0.9 mb from LiIO₃ and LiNbO₃, respectively. They are in good mutual agreement. Finally, based on the

1) Measurement of the Larmor frequency and electric field gradient

As a first step, the Larmor frequency of ¹²B in Mg was measured. Fig. 5-27 shows the NMR spectrum of the DQ transition at the temperature T \sim 100K. The external field was $H_0 = 7$ kOe. The condition of the applied monochromatic rf was $H_1 = 7.7$ Oe. The second component had been



Figure 5-27 Detection of DQ transition of ¹²B in Mg with a monochromatic rf.

The double quantum transition frequency was detected by β -NMR method. The solid curve is the theoretical best fit to the data.

observed at a higher frequency relative to the main peak. The existence of two components for ¹²B in Mg was reported by Kitagawa [Ki90, Ki93c]. The spectrum was analyzed by fitting a Lorentzian or a Gaussian to the data. The fitting results are listed in Table 5-9. The widths of these results are consistent with the dipolar broadening as well as the contribution from the rf intensity. The maintained polarization was consistent with the observed value in Pt under the same condition of the recoil angle $(13\pm8^\circ)$. A typical NMR spectrum of ¹²B in Pt is shown in Fig. 5-28.

Table 5-9

Fitting results of the double quantum transition of ¹²B in Mg and the single quantum transition of ^{12}B in Pt at T ~ 100K and T ~ 300K. The external field was $H_0 = 7$ kOe and 4 kOe.

| Function type | Center frequency (kHz) | Width (kHz) | χ^2 |
|---------------------------------------|------------------------|-----------------|----------|
| Mg | | 1 | |
| $H_0 = 7 \text{ kOe} (\text{T} \cdot$ | ~ 100K) | | |
| Lorentzian | 5358.60 ± 0.05 | 0.76 ± 0.11 | 0.74 |
| Gaussian | 5358.59 ± 0.05 | 0.74 ± 0.07 | 0.78 |
| $H_0 = 4 \text{ kOe} (\text{T} \cdot$ | ~ 300K) | | |
| Lorentzian | 3061.68 ± 0.03 | 0.95 ± 0.06 | 0.53 |
| Gaussian | 3061.69 ± 0.03 | 1.06 ± 0.05 | 1.27 |
| Pt $H_0 = 7 \text{ kOe} (T - T)$ | ~ 100K) | | |
| Lorentzian | 5354.33 ± 0.03 | 0.54 ± 0.04 | 0.75 |
| Gaussian | 5354.32 ± 0.03 | 0.63 ± 0.04 | 0.59 |
| $H_0 = 4 \text{ kOe} (\text{T} -$ | - 300K) | | |
| Lorentzian | 3059.10 ± 0.08 | 1.13 ± 0.12 | 0.71 |
| Gaussian | 3059.11 ± 0.08 | 1.33 ± 0.11 | 1.04 |

| Function type | Center frequency (kHz) | Width (kHz) | χ^2 |
|--|---------------------------|-----------------|----------|
| Mg | Part of the second | - | |
| $H_0 = 7 \text{ kOe} (\text{T} \cdot$ | ~ 100K) | | |
| Lorentzian | 5358.60 ± 0.05 | 0.76 ± 0.11 | 0.74 |
| Gaussian $H_0 = 4 \text{ kOe} (T \cdot$ | 5358.59 ± 0.05 ~ 300K) | 0.74 ± 0.07 | 0.78 |
| Lorentzian | 3061.68 ± 0.03 | 0.95 ± 0.06 | 0.53 |
| Gaussian | 3061.69 ± 0.03 | 1.06 ± 0.05 | 1.27 |
| Pt $H_0 = 7 \text{ kOe} (T - T)$ | ~ 100K) | | |
| Lorentzian | 5354.33 ± 0.03 | 0.54 ± 0.04 | 0.75 |
| Gaussian | 5354.32 ± 0.03 | 0.63 ± 0.04 | 0.59 |
| $H_0 = 4 \text{ kOe} (\text{T} -$ | - 300K) | | |
| Lorentzian | 3059.10 ± 0.08 | 1.13 ± 0.12 | 0.71 |
| Gaussian | 3059.11 ± 0.08 | 1.33 ± 0.11 | 1.04 |

| Function type | Center frequency (kHz) | Width (kHz) | χ^2 |
|---|--|-----------------|----------|
| Mg | A CONTRACTOR OF THE OWNER OWNER OF THE OWNER OF THE OWNER OWNE | 1 | |
| $H_0 = 7 \text{ kOe} (\text{T} -$ | ~ 100K) | | |
| Lorentzian | 5358.60 ± 0.05 | 0.76 ± 0.11 | 0.74 |
| Gaussian $H_0 = 4 \text{ kOe} (\text{T} -$ | 5358.59 ± 0.05 - 300K) | 0.74 ± 0.07 | 0.78 |
| Lorentzian | 3061.68 ± 0.03 | 0.95 ± 0.06 | 0.53 |
| Gaussian | 3061.69 ± 0.03 | 1.06 ± 0.05 | 1.27 |
| Pt $H_0 = 7 \text{ kOe} (T \sim$ | - 100K) | | |
| Lorentzian | 5354.33 ± 0.03 | 0.54 ± 0.04 | 0.75 |
| Gaussian | 5354.32 ± 0.03 | 0.63 ± 0.04 | 0.59 |
| $H_0 = 4 \text{ kOe} (\text{T} \sim$ | - 300K) | | |
| Lorentzian | 3059.10 ± 0.08 | 1.13 ± 0.12 | 0.71 |
| Gaussian | 3059.11 ± 0.08 | 1.33 ± 0.11 | 1.04 |



Frequency (kHz)

Figure 5-28 Typical β -NMR spectrum of ¹²B in Pt with a monochromatic rf.

The solid curve is the theoretical best fit to the data.

It is very interesting that the Knight shift of ¹²B in Mg relative to that in Pt is very large ($(v(Mg) - v(Pt)) / v(Pt) = 8.0 \times 10^{-4}$), which is comparable with other measurement in metals. Table 5-10 shows the Knight shifts of ¹²B in several metals.

Table 5-10

Knight shifts of ¹²B in metals. The definition of the Knight shift is relative to the magnetic field in Pt, K' = (v(M) - v(Pt)) / v(Pt).

| Metal | K' (×10-4) | ref. |
|----------|--------------------|------------------|
| Mg | 8.0(2.0) | present |
| Cu | 6.5(1.9) | [Su67] |
| Au Au | 6.5(1.6) 7.3(8) | [Su67] [We68] |
| Pd | -0.8(8) | [We68] |

the external field and the *c*-axis of the Mg crystal was $\beta = 0^{\circ}$. The due to the symmetry of the Mg crystal structure. The intensity of the component with a half coupling constant has been clearly seen. This component is discussed together with the case of ⁸B in Mg in the

The spectrum for ¹²B in Mg was observed by the NNQR method (Fig. 5-29). The external magnetic field was $H_0 = 4$ kOe, and the angle between asymmetry factor (η) of the electric field gradient is expected to be zero applied monochromatic rf field was 0.4 Oe. The solid lines represent the theoretical case best fit to the data. In the spectrum of ¹²B, the second Appendix. The coupling constant of ¹²B was obtained from the main peaks as $|eqQ/h| (^{12}B \text{ in Mg})| = 46.4 \pm 0.4 \text{ kHz}$. The present result is consistent



Figure 5-29 Typical NNQR spectrum of ¹²B in Mg. The solid curve is the theoretical spectrum best fit to the data. There are two component in the spectrum. The small component at the lower frequency is considered to be come from crystallographical disorders near the surface. See Appendix.

with the previous value |eqQ/h| (¹²B in Mg)| = 47.0 ± 0.1 kHz based on a detailed study of ¹²B in Mg by Kitagawa [Ki93c]. Here, we adopt the previous value because of its high precision.

2) β -NMR detection of ⁸B

From the study of Knight shift for ¹²B in Mg, the Larmor frequency of ⁸B in Mg was deduced. Using this value, the electric quadrupole coupling frequency (v_0) was measured by the NNQR method at room temperature. Fig. 5-30 shows the spectrum for ⁸B in Mg. The external magnetic field was $H_0 = 7$ kOe. The angle between the external field and the *c*-axis of the Mg crystal was $\beta = 0^{\circ}$. The intensity of the applied rf field was 9 Oe. The FM widths were ± 5 kHz for inner rf's and ± 15 kHz for outer rf's. The solid lines are for the theoretical case best fit to the data. The coupling constant was obtained as $|eqQ/h| (^{8}B \text{ in Mg})| = 243.6 \pm 6.0 \text{ kHz}$. The small peak at lower frequency is due to partial depolarization, which means that a pair of outer rf's destroyed the inner resonance peaks (see Chapter 3-2-6 and Fig. 3-15a).

In contrast to the case of ¹²B, no significant peak corresponding to the second component (more than 5% population) has been observed for the ⁸B case. The main difference in these two cases is the implantation ranges of the nuclei in the crystal. The maximum depth of ⁸B is about 3.4µm, while that of ¹²B is just 1.5µm. Crystallographical disorders near to the surface might be the cause of the second population.

3) Electric quadrupole moment of ⁸B

in Mg was determined to be $|q(B \text{ in Mg})| = (1.48 \pm 0.03) \times 10^{20} \text{ V/m}^2$.

The quadrupole moment of ¹²B is $|Q(^{12}B)| = 13.20 \pm 0.25$ mb based on the present study. Using this quadrupole moment, the electric field gradient with the present value by Cold (11) to Mark a 41.0 and 1 and the first state benefits thread states of 100 in Mark by Mingraws (Kolda), thread states of 100 in Mark by Mingraws (Kolda), thread states of 100 in Mark by Mingraws (Kolda), thread states of 100 in Mark by Mingraws (Kolda), the second states of 100 in Mark



Figure 5-30 Typical NNQR spectrum of ⁸B in Mg. The quadrupole coupling constant of ⁸B in Mg was detected by use of the NNQR method. The solid curve is the theoretical spectrum best fit to the data. The horizontal bar in the figure shows the FM width.

The quadragesic motions of ¹²B is Q(¹²B); = 11.20 ± 0.25 minimum on the present study. Uning this quadrapole moment, the statute (refs gold in the Mg way determined to be in Mg); = (1.68 ± 0.09) × 16¹⁰ Vigit Thus, the electric quadrupole model 68.7 ± 2.1 mb.

Thus, the electric quadrupole moment of ⁸B was deduced to be $|Q(^{8}B)| =$

Chapter 6

DISCUSSION

6-1 Hyperfine interactions of ⁸Li in LiIO₃ and LiNbO₃ and quadrupole moment of ⁸Li

A long-standing open question about the discrepancy in the experimental $Q(^{8}Li, 2^{+})$ has been decisively ended by the present NNQR detection of ⁸Li and the FT-NMR detection of ⁷Li in LiIO₃ and LiNbO₃ crystals. The coupling constants of ⁸Li in the substitutional sites of the single crystals of LiIO3 and LiNbO3 were determined as $leqQ(^{8}Li;LiIO_{3})/hl = 29.6 \pm 1.1 \text{ kHz and } leqQ(^{8}Li;LiNbO_{3})/hl = 44.68 \pm 1.1 \text{ kHz and } leqQ(^{8}Li)/hl = 4.1 \text{ kHz and } leQQ(^{8}Li)/hl$ 0.88 kHz, respectively. These values are in quite good agreement with the known values [Ac74, Mi75]. The field gradients in the substitutional sites of both crystals were remeasured by the FT-NMR method at high fields as $leqQ(^7Li;LiIO_3)/hl = 36.4 \pm 0.5$ kHz and $leqQ(^7Li;LiNbO_3)/hl = 53.3 \pm 0.5$ 0.5 kHz for each crystal. It is clear now that the cause of the above mentioned discrepancy was due to the incorrect leqQ(7Li;LiIO3)/hl data [Sa72]. Using the recently determined value of $Q(^{7}Li) = -40.0 \pm 0.6$ mb [Vo91], $Q(^{8}Li, 2^{+})$ were determined to be $|Q(^{8}Li, 2^{+})| = 32.6 \pm 1.4 \text{ mb}$, and 33.5 ± 0.9 mb from the runs using these two catchers (Table 6-1). From the average of these two values, $|Q(^{8}Li,2^{+})| = 32.7 \pm 0.6$ mb, was determined as the final result.

6-2 Quadrupole moment of ¹²N and its hyperfine interactions Another question about the $Q(^{12}N, 1^+)$ value was solved by the present NNQR detection of ¹²N and the FT-NMR detection of ¹⁴N in BN and GaN crystals, and $|Q(^{12}N, 1^+)| = 10.3 \pm 0.7$ mb was determined. This value is in quite good agreement with the expected value $(Q(^{12}N) \sim 10)$

Table 6-1 Parameters used for the measurements of the quadrupole moments.

| $A(I^{\pi})$ | Catch | ner To | emp | erati | ıre(K |) $leqQ/$ | hl (| (kHz) | Reference |
|--|-------|--------|-----|-------|-------|-----------|------|-------|-----------|
| ⁸ Li(2 ⁺) | LiIC |)3 | ~3 | 00 | 195 | 29.6 | ± | 1.1 | present |
| | | | | | | 29.2 | ± | 0.8 | [Mi75] |
| | LiN | 603 | ~3 | 00 | | 44.68 | ± | 0.88 | present |
| | | | | | | 43 | ± | 3 | [Ak74] |
| ⁷ Li(3/2 ⁻) | LiIC |)3 | ~3 | 00 | | 36.4 | ± | 0.5 | present |
| | | | | | | 44 | ± | 3 | [Sa72] |
| | LiN | 003 | ~3 | 00 | | 53.3 | ± | 0.5 | present |
| | | | | | | 54.5 | ± | 0.5 | [Ak74] |
| $ Q(^{8}\text{Li};\text{LiIO}_{3}) =$ | | 32.6 | ± | 1.4 | mb | | | | |
| IQ(8Li;LiNbO3) | = | 33.5 | ± | 0.9 | mb | | | | |
| $ Q(8Li;2^+) =$ | | 32.7 | ± | 0.6 | mb | | | | |
| 1 | - | | | | | | | | |
| ¹¹ B(3/2 ⁻) | BN | | ~3 | 00 | 2 | 902 | ± | 12 | present |
| | | | | | 2 | 960 | ± | 100 | [Si60] |
| | BN | | | 4.2 | 2 | 934 | ± | 4 | [Co90] |
| $^{12}B(1^{+})$ | BN | | ~31 | 00 | | 944 | ± | 17 | present |
| | Mg | | ~10 | 00 | | 47.0 | ± | 0.1 | [Ki93] |
| ⁸ B(2 ⁺) | Mg | | ~10 | 00 | | 243.6 | ± | 6.0 | present |
| $Q(^{12}B, 1^+) =$ | | 13.20 | ± | 0.25 | mb | | | | |
| $Q(^{8}B,2^{+}) =$ | | 68.3 | ± | 2.1 | mb | | _ | | |
| | | | | 1 | | | | | |
| 12N(1+) | BN | | ~30 | 00 | | 56.8 | ± | 3.2 | present |
| | GaN | | ~30 | 00 | | 27.5 | ± | 2.0 | present |
| $^{14}N(1+)$ | BN | | ~30 | 00 | | 110.7 | ± | 4.1 | present |
| | GaN | | ~3(| 00 | | 49 | ± | 15 | present |
| $Q(^{12}N, 1^+) =$ | | 10.3 | ± | 0.7 | mb | | | | |

mb) based on a study of the hyperfine interactions of ¹²N in metals by Minamisono [Mi70].

Furthermore, Akai predicted the field gradient at ¹²N site in Mg crystal. Therefore the quadrupole moment $Q(^{12}N)$ was extracted using the experimental $eqQ(^{12}N)$ value of ¹²N in the Mg crystal [Oh93]. His calculation of the electric field gradient based on a KKR band structure calculation as summarized in the Appendix B. The field gradient was suggested as being $q = -1.92 \times 10^{20}$ V/m². The quadrupole moment was obtained as being $Q(^{12}N) = 12.7$ mb using the observed quadrupole coupling constant $eqQ/h(^{12}N \text{ in } Mg) = -59.3 \pm 1.0$ kHz [Ki90]. It is in good agreement with the present experimental result. This agreement shows that the theoretical method is powerful for studying the electronic structure of a dilute impurity at an interstitial site in metals.

On the other hand, the value deduced based on pion photoproduction $(Q(^{12}N) = +49mb)$ is much larger than the present value [Ra80]. This discrepancy may be due to the cross-section data being inadequate used to deduce an quadrupole moment.

6-3 Proton halo in ⁸B discovered by its quadrupole moment

The nuclear quadrupole moment of a state is separated into two matrix elements ($\hat{Q}(N_p)$ and $\hat{Q}(N_n)$) by the proton-neutron formalism [Ki93a] (Table 6-2):

$$Q(N_p, N_n) = \sqrt{\frac{16\pi}{5}} \left[\left\langle \sum e_n^{eff} \left(\frac{1}{2} + t_z \right) r_i^2 Y_{20} \left(\Omega_i \right) \right\rangle + \left\langle \sum e_p^{eff} \left(\frac{1}{2} - t_z \right) r_i^2 Y_{20} \left(\Omega_i \right) \right\rangle \right]$$
$$= e_n^{eff} \hat{Q}(N_n) + e_p^{eff} \hat{Q}(N_p)$$

where t_z is the z component of the isospin operator. The effective charges e_p^{eff} and e_n^{eff} of the proton and the neutron in light nuclei were obtained by Kitagawa and Sagawa as $e_p^{eff} = +1.25$ and $e_n^{eff} = +0.47$ [Ki93a], respectively.

The theoretical values were calculated using the empirical effective charge of the protons and neutrons $(e_{p}eff=1.25, e_{n}eff=0.47)$ [Ki93a]. The quadrupole moments are given in absolute values. Theoretical and experimental quadrupole moments of the nucleus in A=8, 11, 12 systems.

Table 6-2

| ANucleusInQuadrupole moment (mb)RefereAHOWSexperimentB 2^+ 27.0 30.7 32.6 ± 0.7 8 2^+ 48.8 75.0 68.7 ± 2.1 9 reser | | | | | | | |
|--|---|---------|----|-----------|----------------|----------------|--------|
| HO WS experiment 8 8Li 2+ 27.0 30.7 32.6 ± 0.7 preser 8 2+ 48.8 75.0 68.7 ± 2.1 preser | A | Nucleus | Ιπ | Quadrupol | le moment (mb) | | Refere |
| 8 8Li 2+ 27.0 30.7 32.6 ± 0.7 preser 8 2+ 48.8 75.0 68.7 ± 2.1 preser | | | | HO | SW | experiment | 1 |
| ⁸ B 2 ⁺ 48.8 75.0 68.7±2.1 preser | 8 | 8Li | 2+ | 27.0 | 30.7 | 32.6 ± 0.7 | preser |
| | | 8B | 2+ | 48.8 | 75.0 | 68.7 ± 2.1 | preser |

nce

| [Su91] [Su92] | present |
|-------------------|--------------|
| $+40.59 \pm 0.10$ | 13.20 ± 0.25 |
| $+33.27 \pm 0.24$ | 10.3 ± 0.7 |
| 39.0 | 16.2 |
| 29.4 | 5.2 |
| 58.9 | 26.1 |
| 38.7 | 11.2 |
| 3/2- 3/2- | 1+ |
| 11B | 12B |
| 11C | 12N |
| 11 | 12 |

At first, we considered the A = 8 system. The density distributions of protons and neutrons in ⁸B as a function of the radius were calculated using the Cohen-Kurath (CK) shell-model wavefunctions in the Woods-Saxon (WS) potential (Fig. 6-1). The parameters of the Woods-Saxon potential were taken from ref. [Bo69], except for the potential depth. The depth was adjusted so as to reproduce the experimental separation energy of a single nucleon in each shell-model configuration [Ki93a]. The proton distribution in ⁸B (solid line) shows a substantial radial swelling, which overcomes the Coulomb and centrifugal barriers, compared with the neutron distribution (dashed line). Since the densities near to the surface are mainly due to the valence nucleons, as indicated by the dotted lines, the value of $\hat{Q}_{th}(N)$ reflects the distribution of the valence nucleons. The shell-model calculation is reliable for predicting the $\hat{Q}_{th}(N)$ for the deeply bound nucleons, and gives the same value of $\hat{Q}_{\text{th}}(3) = 8.0$ mb for the three-neutron configuration in ⁸B. We were therefore able to extract the value for five protons in the ⁸B nucleus semiempirically as

 $\hat{Q}_{emp}(5; {}^{8}B) = [Q_{exp}({}^{8}B) - e_n eff \hat{Q}_{th}(3)] / e_p eff$ $= [68.7 - 0.47 \times 8.0] / 1.25$ = 49.8 mb.

If the five protons were deeply bound, since the conventional shell model with Harmonic oscillator potential predicts that $\hat{Q}_{th}(5)[HO] = 24.3$ mb, the $\hat{Q}(5)$ obtained empirically is twice as large as the theoretical value. Taking into account the proton separation energy, and therefore the halo effect in ⁸B, we obtained an improved theoretical of $\hat{Q}_{th}(5)$ [WS] = 58.1 mb which agrees perfectly with the present empirical value. Using the present wavefunction, the rms radii for protons and neutrons in ⁸B were calculated with the halo effect. The rms radius $\langle r^2 \rangle_p ^{1/2} = 3.03$ fm for protons is much larger than the $\langle r^2 \rangle_n^{1/2} = 2.16$ fm for a threeneutron core (Table 6-3). This is a clear evidence of a proton halo





distributions, respectively. The dotted curves are those for valence



Figure 6-2 Density distribution of protons and neutrons in ⁸Li nuclei. The solid and broken curves correspond to proton and neutron distributions, respectively. The dotted curves are those for valence nucleons.

Table 6-3

Root-mean-square (rms) radii of the proton and neutron distributions in nuclei of A=8, 11,12 systems. The rms radii for the total mass are also given. [Ki93a]

| A | Nucleus | Wavefunctions | Radius (fm) | | | | |
|----|-----------------|---------------|-------------|---------|------|--|--|
| | a login là | 6-6 96 Wiles | proton | neutron | mass | | |
| 8 | 8B | НО | 2.32 | 2.16 | 2.26 | | |
| | | WS | 3.03 | 2.16 | 2.74 | | |
| | ⁸ Li | WS | 2.16 | 2.73 | 2.53 | | |
| 11 | 11B | НО | 2.40 | 2.43 | 2.42 | | |
| | | WS | 2.39 | 2.47 | 2.43 | | |
| | 11C | WS | 2.51 | 2.38 | 2.45 | | |
| 12 | 12B | HO | 2.42 | 2.48 | 2.46 | | |
| | | WS | 2.41 | 2.68 | 2.57 | | |
| | 12N | WS | 2.80 | 2.42 | 2.65 | | |

Table 6-4

Calculation of the rms radii of the proton and neutron distributions in the nuclei of A=8.

| Nucleus | <i>Q</i> (mb) | -a-dress | Radius (f proton | m) neutron | mass | 0. 4 d |
|-----------------|-----------------------|------------------------------|----------------------------|----------------------|--------------|------------------|
| 8B | 65.8 75.0 | cluster model shell model | 2.74 3.03 | 2.25 2.16 | 2.57 2.74 | [Cs93] [Ki93] |
| ⁸ Li | 22.5 30.7 | cluster model shell model | 2.20 2.16 | 2.59 2.73 | 2.45 2.53 | [Cs93] [Ki93] |
| Nucleus | Service S dotter t | | Radius (fm) last proton | ⁷ Be core | mass | - |
| 8B | 1000 | | 3.75 | 2.33 | 2.51 | [Ri93] |

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covering the 7Be core in 8B. The present rms radius for protons in 8B is about 20% larger than the value of $\langle r^2 \rangle_p ^{1/2} = 2.45$ fm determined based on the interaction cross sections using a radioactive beam of 800 AMeV ⁸B [Ta88]. This discrepancy may be due to that the interaction cross section method in the high-energy region is not sensitive to such a low amplitude of the present halo distribution.

6-4 Neutron skins in ⁸Li and ¹²B detected by their quadrupole moments

As the next step, we considered ⁸Li as having a normal bound last proton $(E_{sp}(p) = 12.5 \text{ MeV})$ and a rather shallowly bound last neutron $(E_{sp}(n) = 2.0 \text{ MeV})$. The density distributions of the protons and neutrons in ⁸Li as function of the radius were calculated by using the Cohen-Kurath (CK) shell-model wavefunctions in the Woods-Saxon (WS) potential (Fig. 6-2).

The theoretical value for five neutrons $\hat{Q}_{th}(5) = 41.6$ mb which completely accounts for the value which is deduced from the experimental value $|Q_{exp}(^{8}Li,2+)| = 32.7 \pm 0.6$ mb as following. As well as ⁸B, the semiempirical value of $\hat{Q}(5)$ can be extracted as

$$\hat{Q}_{emp}(5; {}^{8}\text{Li}) = [Q_{exp}({}^{8}\text{Li};2^{+}) - e_{p}{}^{eff}\hat{Q}_{th}(3)] / e_{n}{}^{eff}$$

= [32.7 - 1.25 × 8.0] / 0.47
=48.3 mb .

The theoretical $\hat{Q}_{th}(5)[HO] = 24.3$ mb with a harmonic-oscillator potential is about half the empirical value, while the $\hat{Q}_{th}(5)[WS] = 41.6$ mb with Woods-Saxon potential is in good agreement with the empirical value. The rms radii, $\langle r^2 \rangle_p ^{1/2} = 2.16$ fm and $\langle r^2 \rangle_n ^{1/2} = 2.72$, were obtained theoretically while taking into account the halo effect, which shows a significant difference between the proton and neutron radial distribution (Table 6-3). This suggests a thin neutron skin covering the

⁷Li core. Here, we use the word "skin" when the difference between The present rms radius for neutrons in ⁸Li is also larger than the value [Ta88]. Similarly, from the nuclear interaction cross section measured at

 $< r^2 >_p ^{1/2}$ and $< r^2 >_n ^{1/2}$ is rather smaller than the case of ⁸B (0.9 fm). of $\langle r^2 \rangle_n^{1/2} = 2.44$ fm determined from the interaction cross section far low energies (25~65 AMeV) at GANIL [Li90], rms radii are determined as $\langle r^2 \rangle_p ^{1/2} = 2.17$ and $\langle r^2 \rangle_n ^{1/2} = 2.80$ fm. These radii are in quite good agreement with the present result; $\langle r^2 \rangle_p^{1/2} = 2.16$ fm and $\langle r^2 \rangle_n^{1/2} = 2.72$ fm. These agreements show the importance of studies on the energy dependence of the interaction cross section at low energies.

model calculation concerning this system, $\hat{Q}_{th}(5)[WS] = 13$ mb and its finite value is due to configuration-mixing corrections.

These values give quadrupole moments of $Q(^{12}B)[WS] = 16.2 \text{ mb as}$ shown in Table 6-2. This theoretical value is in good agreement with the present experimental value $|Q_{exp}(^{12}B)| = 13.20 \pm 0.25$ mb. On the contrary, the shell model using harmonic-oscillator potential gives $Q(^{12}B)[HO] = 26.2 \text{ mb}$, which is in poor agreement with the experiment. This tendency is similar to the case of the A = 8 system.

The calculated rms radii of the protons and neutrons in ¹²B with loosely bound neutrons, $< r^2 >_n 1/2 = 2.68$ fm and $< r^2 >_p 1/2 = 2.41$ fm (Table 6-3) show a thin neutron skin covering the ¹¹B core. The radii derived from the interaction cross section at ¹²B energy of 800 AMeV $< r^2 >_n 1/2 = 2.42$ fm and $< r^2 >_p 1/2 = 2.35$ fm [Ta88] are both smaller than the present values. On the other hand, the radii determined using low

We next consider the A = 12 system (¹²B and ¹²N). Based on a shell- $\hat{Q}_{\text{th}}(7)[\text{WS}] = 0.11$ mb were obtained using the Wood-Saxon potential for both the proton and neutron groups, respectively. The small value for the $\hat{Q}(7)$ [WS] is because the valence nucleon is mainly in the p_{1/2} state, and

energies (25~65 AMeV) are rather large, $\langle r^2 \rangle_n^{1/2} = 2.93$ fm and $\langle r^2 \rangle_p ^{1/2} = 2.40$ fm [Li90] which are in good agreement with the present results. This tendency is the same as in the case of ⁸Li. The importance of the energy dependence of the interaction cross section has been also suggested by Fukuda et al. in the interpretation of interaction cross section of ¹¹Be [Fu91].

6-5 Quadrupole moment of ¹²N

Finally, we consider the rms radius of ¹²N (Table 6-2). Using the values of $\hat{Q}_{\text{th}}(5)$ [WS] and $\hat{Q}_{\text{th}}(7)$ [WS], the quadrupole moment of ¹²N is given as $Q(^{12}N)[WS] = 5.2$ mb. This result is about 1/2 of the experimental value, and is not in agreement with the experiment one. On the contrary, the shell model using the harmonic-oscillator potential gives $Q(^{12}N)[HO] = 11.2 \text{ mb}$, which is in good agreement with the experimental values. This tendency differs from the other cases (8Li, 8B and 12B).

Here, we consider the case of the A = 11 system, where both nuclei (¹¹B and ¹¹C) have a deeply bound last proton and neutron. These calculation values are listed in Table 6-2. The results show that a calculation using the Cohen-Kurath potential is better than using the harmonic-oscillator potential in the case that there is no halo structure.

Even though the present theoretical calculation was successful for other nuclei (8Li, 8B, 11B, 11C and 12B), there is a discrepancy in the quadrupole moment between the theoretical calculation with a halo structure and the experimental result in the case of ¹²N. This may be due to an inadequacy of the theoretical calculation for ¹²N.

for ⁸Li and ⁸B

In this section we introduce other theoretical descriptions for nuclear quadrupole moments and radii.

fitting of the experimental energy levels of A = 6-16 nuclei. They sufficiently suitable. A reconsideration of their description might therefore be necessary.

They deduced the quadrupole moments as being $Q(^{8}Li) = 31$ mb and values. On the other hand, another report concerning a three-cluster moments as being $Q(^{8}\text{Li}) = 22.5 \text{ mb}$ and $Q(^{8}\text{B}) = 65.8 \text{ mb}$. Although

6-6 Other interpretations of the quadrupole moments and radii

Nakada et al. [Na93] discussed the E2 properties of A = 6-10 nuclei with a $(0+2)\hbar w$ large-scaled shell-model calculation that was developed by Wolter et al. [Wo90]. The effective interaction was determined by a calculated the quadrupole moments of ⁸Li and ⁸B using small effective charges ($e_p eff = 1.05$ and $e_n eff = 0.05$) as being $Q(^8\text{Li}) = 32.1$ mb and $Q(^{8}B) = 62.7$ mb without introducing any halo structures. These values are in good agreement with the experiments. They mentioned that the small effective charges may be due to the slower damping tail of the proton density, even though its amplitude is smaller than ones of ¹¹Li and ¹¹Be. However, nuclear radius calculated in this model is larger than one obtained based on the interaction cross section [Sa94]. Furthermore, it must be noted that in their view the core excitation (deformation) occurs considerably, even in the region which has been considered spherical region. This means that the wavefunctions that they used may not be

Descouvemont et al. reported on a theoretical study of ⁸Li and ⁸B within the framework of the cluster model [De92]. They described ⁸B and ⁸Li as being three-cluster systems: ⁸Li = α + t + n and ⁸B = α + ³He + p. $Q(^{8}B) = 73$ mb. These values are in good agreement with experimental calculation was carried out by Csótó [Cs93]. He deduced the quadrupole

 $Q(^{8}B)$ is in good agreement with the experimental value, $Q(^{8}Li)$ is rather inconsistent. This discrepancy is not discussed in his paper. These results show that the three-cluster model provides a good description for these nuclei, even though there is a slight discrepancy. Furthermore, Csótó calculated the rms radii for protons and neutrons in ⁸Li and ⁸B using the three-cluster model. These values are listed in Table 6-4. Although their results show the existence of neutron and proton skins, these amplitudes are rather smaller than our. It is very interesting that the neutron and proton skins have been deduced from different approaches: the shell model and the cluster model.

In astrophysics nuclear radius have an important role. The radius of ⁸B has been discussed concerning the "solar neutrino problem" by Riisager et al. [Ri93]. It is the long-standing discrepancy between the experimentally and theoretically calculated neutrino flux from the Sun [Ba82]. If the contribution from ⁸B neutrinos were half the presently assumed values, the theory and experiments would agree within a few standard deviations. They looked at the ${}^{7}Be(p, \gamma){}^{8}B$ reaction through which ${}^{8}B$ is produced in the Sun. The tail of the proton distribution is important concerning the rate of the $^{7}Be(p, \gamma)^{8}B$ reaction at low energies and the high-energy solar neutrino flux. The proton capture reaction can be used as a probe for nuclear radii. They calculated the astrophysical S-factor of this reaction as well as the rms radii for ⁸B. They used a two-body model for ⁸B, which is considered to be approximated by a proton bound in the weak field from a 7Be-like core [Ri92, Je92]. The potential is assumed to be a gaussian of range b = 1.90 fm and the strength is varied to adjust the proton separation energies $E_{sp}(p)$. They pointed out the importance of the separation energy of the last proton in ⁸B. The rms radius for ⁸B for the experimental separation energy was 2.51 fm and the corresponding rms radius for the last proton was 3.75 fm (Table 6-4). Although the value

was quite a bit larger than the deduced rms radius of their ⁷Be core (2.33 fm) their result phenomenologically shows an existence of a proton skin in ^{8}B .

Chapter 7

SUMMARY

We measured the quadrupole moments of ⁸Li, ⁸B, ¹²B and ¹²N using a modified β -NMR (NNQR) method. The results are $|Q(^{8}Li)| = 32.7 \pm 0.6$ mb, $|Q(^{8}B)| = 68.3 \pm 2.1$ mb, $|Q(^{12}B)| = 13.20 \pm 0.25$ mb and $|Q(^{12}N)| =$ 10.3 ± 0.7 mb. These values were mostly accounted for fairly well by the effect of spatial swelling in the distributions of shallowly bound valence nucleons. Above all, the neutron distributions of ⁸Li and ¹²B are in quite good agreement with that deduced based on the interaction cross sections measured at low energies. A prominent proton halo is suggested to cover the 7Be core, in spite of the existence of Coulomb and centrifugal barriers in ⁸B. The measurement of the nuclear interaction cross sections at low energies for proton-rich nuclei is planed in order to clarify the present picture. The implication of the quadrupole moment of ¹²N, which is twice as large as the value obtained from the shell model calculation with a halo, has to be disclosed.

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APPENDIX

A. Field gradients in Mg detected by ¹²B and ¹²N

From the detailed study of the electric quadrupole interactions for ¹²B and ¹²N using the β-NMR method [Ki90, Ki93c] there are two components in the NMR spectrum (Fig. 5-29). Amount of the main component is about 80% and one of the sub component is about 20%. The main electric field gradient is confirmed that it is parallel to the c-axis. In the condition of $\beta = 0^{\circ}$, the sub component shows that the sign of the field gradient is inverse relation to the main component and its amplitude is about an half of one of main component. These results suggest that both component are same sites in the crystal but local directions of the small crystal block are different. The study of ⁸B whose recoil energy is larger than ¹²B (Table) showed that this phenomenon is occurred in surface of crystal (<1µm), since the implantation process is similar for both nuclei. It is considered to be due to the process of surface treatment. Further study of ¹²B in Mg [Mi94], the field-gradient direction of the sub component is not distributed homogeneously but considered to be restricted. One interpretation is that in surface local crystal blocks are restricted and the direction of its c-axis is normal to the plane when main c-axis is contained in the plane. Now, further study is in progress in our laboratory.

B. Theoretical calculation of the field gradient at the trigonal site of Mg and the nuclear quadrupole moment of ¹²N

While a number of theoretical studies have been made on substitutional impurities in metallic system in the past decade, little has been done for interstitial impurities such as ¹²B and ¹²N in Mg. The main reason is that,

whereas lattice relaxations are crucial for most interstitial impurity systems, the Korringa-Kohn-Rostoker (KKR) Green function method, a standard method of the electronic structure calculation of impurity system, cannot treat the effect of the lattice relaxations property. One of the way to avoid the difficulty is to use the super-cell method. Though obviously the super-cell method is not the best choice for the impurity in an unrelaxed lattice, the method is quite powerful in general because of its capability of handling arbitrary rearrangements of atoms around the impurity.

Akai et al. performed the KKR band structure calculation in the framework of the local-density approximation (LDA) on super-cells illustrated in Fig. A-1. To include the effects of the lattice relaxation around the impurity, they displace the nearest neighboring host atoms, keeping the local symmetry around the impurity unchanged, as is shown in Fig. A-1 by the arrows. In order to make direct comparisons of the total energies among various impurity locations and lattice relaxations possible, they fix the muffin-tin radii to values somewhat smaller than those for touching spheres so that they never intersect. The total energy of the system is calculated for various lattice relaxations, which gives the energy as a function of the relaxation. In Fig. A-2 the calculated total energies for various N locations are compared.

As is naturally expected, the location of N with the lowest energy is the octahedral-like (O-site) which has the biggest interstitial volume. The tetrahedral-like site (T-site) also has a rather big interstitial volume. The energy for this location, however, is the highest, 5.5 eV relative to the O-site case. Between two trigonal sites, the center of the basal triangle just below the O-site(Trig1-site) gives a lower energy, being 0.83 eV relative to the O-site and Trig1-site cases are 2.6 and 3.7 eV, respectively. The minimum



Trig1 (trigonal 1)





0



(octahedral)

(tetrahedral)

Fig. A-1 Four different types of the unit-cell used in the calculations. The big spheres represent the host atoms and the small filled one represents the impurity atom. The arrows show the direction of the local lattice relaxation for Trig1 and O cases.

O Mg

N (impurity)



Octahedral

Fig. A-2 Energy scheme indicating the relative energies per unit cell (in eV) for various site occupations of N impurities in Mg. Also shown are the energies after the full lattice relaxations for the Octahedral and Trigonal 1 cases.

5.5 eV

4.2 eV

Tetrahedral

Trigonal 2

3.7 eV ∆/a~0.17

relaxation

Trigonal 1

occurs at $\Delta a \sim 0.06$ (O-site) and ~0.17 (Trig1-site), respectively, where Δ is the displacement of the neighboring Mg atoms and a is the lattice constant.

As for the location and the lattice relaxation of N impurities in Mg, Kitagawa et al. concluded from their experiments on orientation dependence of the dipolar broadening of the NMR spectrum that the impurity location was either Trig1 or Trig2 with a local lattice expansion than their observation.

Akai et al. calculated electric field gradient at the N nucleus. At the equilibrium lattice expansion ($\Delta a = 0.17$), $q = -1.92 \times 10^{20}$ V/m² is obtained. This corresponding to the nuclear quadrupole moment of +12.7 mb, if the quadrupole coupling constant of -59.3 ± 0.1 kHz for ¹²N is used. This value is in good agreement with the present experimental value.

Though, they were not very confident of the absolute value since the variation of q against the relaxation is really large and also its convergence with respect to the number of k-point sampling is slow (the results are for 216k-points in the irreducible zone); it seems rather hard to determined the q at the optimum configuration for their system.

data-acquisition system

We list computer programs for β -NMR and NNQR method. These program are written by MASM (macro assembler). They contain two parts, main programs and macro libraries. We list these files in Table A-1

Table A-1

List of the computer programs.

| File name | type | Experiment mode |
|-------------|-----------------|-----------------|
| LABCNTR.BAS | main program | all |
| | (BASIC) | file I/O |
| LABCNTR1 | macro libraries | all |
| LABCNTR2 | macro libraries | all |
| IOCNTR | macro libraries | all |
| | | |
| 2APCNTR | main program | 2AP mode |
| 8APCNTR | main program | 8AP mode |
| 2RFCNTR | main program | 2rf mode |
| 2RFCNTR | main program | 2rf mode |

| e name | type | Experiment mode |
|-----------|-----------------|-----------------|
| BCNTR.BAS | main program | all |
| | (BASIC) | file I/O |
| | | |
| BCNTR1 | macro libraries | all |
| BCNTR2 | macro libraries | all |
| CNTR | macro libraries | all |
| | | |
| PCNTR | main program | 2AP mode |
| PCNTR | main program | 8AP mode |
| FCNTR | main program | 2rf mode |
| | | |

C. A computer program list for NNQR: spin control and

LABCNTR.BAS 10670 NK=1:MC=5:GOSUB *DSPIN 10680 IF ANSN THEN *LDDATA ELSE IF ANSNR=2 THEN GOSUB 10000 *MDLP3 10690 GOSUB *CKRFMAKE:GOSUB *PARAMAKE1:GOSUB *RFDTMAKE 10700 *LDDATA3 10010 experimental control program (operating part) 10710 MC=5:PS=*コメントを入れて下さい*:GOSUB *DSPM 10020 10720 L1=23:C1=24:AS=RNCMNTS:GOSUB *DSPSIN:RNCMNTS=AS 10030 10040 '\cntr\LABCNTR. BAS" 10050 10060 ' by A. Kitagawa Ver 8.30 L.07 '89/03/10 10070 '1992.9.29 modify 21730 to use dif. mode for 2AP by T.Ohtsubo L.08 10075 '1993.4.20 modify 23360 (adding L=0) by T.Yamaguchi 10080 10090 ' 10100 CLEAR 4H500, 4H4D4B, 4H0 10110 PCFRG=1:FMFRG=0 10120 MSEG=SEGPTR(2) 10130 MSEG2-MSEG+6H400 10140 DIM FIMENUS (10), NMMENUS (10), MMENU (10), NSVDATA (10) 10150 DTM RFGP\$ (127), RFDA* (1, 127), NU# (127), UP# (15, 127, 2), DW# (15, 127, 10160 DIM R(15, 127, 2), RER(15, 127, 2), UD(127, 2), ER(127, 2), ERC(127, 2) 10170 DTM RSEC (7, 127, 2), RERSEC (7, 127, 2), EFFECT (127, 2), EFFERR (127, 2) 10180 DIM X(255), Y(255), Z(255), ZC(255), DUMMY1(15) 10190 DIM TWAIT\$ (31), RFDATA\$ (15, 127), U\$ (1, 15, 127, 3), D\$ (1, 15, 127, 3), P ARA (31) 10200 DIM SEM* (1,15) 10210 10220 ON ERROR GOTO *TRAP 10230 ON STOP GOSUB *STTRAP: STOP ON 10240 ' 10250 '+++++ set experimental mode 10260 10270 LBLFRG-0:RFDTFRG-1:NCH-1:TRNSFRG-0:MNTFRG-0 10280 BSTIME-.1:BMCYC-4 10290 10300 DTDRIVES="B:":PRDRIVES="A:":SYDRIVES="A:\cntr\":DTDRIVE=1 10310 GOSUB *SELMENU 10320 IF TRNSFRG THEN OPEN "COM1:N81XN" AS #2 10330 GOSUB *PARAMAKE2 10340 HCFRG=1- (AP4FRG OR AP8FRG) : LPONEFRG%=0 : LPMIN=4 :MAXN3=0 10350 * 10360 '---- loding assembla program 10370 10380 MC-5:GOSUB *DSPWAITMES 10390 GOSUB *LDMPRG 10400 LAB*-0 10410 ' 10420 '+++++ system initialize 10430 10440 *TNIT 10450 MC=4 GOSUB *DSPWAITMES 10460 GOSUB *INITGP:GOSUB *GPLCL 10470 GOSUB *DSPINIT 10480 10490 '+++++ data input 10500 10510 *LDDATA 10520 GOSUB *RNMMAKE: GOSUB *DSPTITLE 10530 MC=5:PS="Run No. を入れて下さい":GOSUB *DSPM 10540 L1-23:C1-30:AS-RNMS:GOSUB *DSPSIN 10550 RNMS=LEFTS (AS, 8) : F=INSTR (RNMS, ".") +INSTR (RNMS, "\") +INSTR (R NMS. ***) 10560 IF F THEN BEEP: GOSUB *CL3: GOTO *LDDATA 10570 GOSUB *DSPTITLE: GOSUB *CL3 10580 PS-*新しいrunですか (0)、再開ですか (1) * 10590 NK-2:MC-5:GOSUB *DSPIN:ANSNR-ANSN+1 10600 ON ANSNR GOSUB *LDNEW, *LDOLD, *LDCNT 10610 10620 *LDDATA2 10630 IF NRES-O THEN *LDDATA

10640 GOSUB *DSPCLTG: GOSUB *DSPTITLE: GOSUB *DSPSET

10650 MC-7:PS-"設定":GOSUB *DSPST

10730 A=INSTR (AS, CHRS (6H22)) : IF A THEN RNCMNTS=LEFTS (AS, A-11 : GOTO *LDDATA3 10740 ' 10750 '++++main loop 10760 ' 10770 *MAINLOOP 10780 GOSUB *DSPCLT:GOSUB *DSPTITLE 10790 MC=5:PS="待機中":GOSUB *DSPST 10800 TESTERG=0 10810 PS=* [0] キーで実行します。(設定変更 [1]、停止 [2]、 テスト [3])* 10820 NK=3:MC=5:GOSUB *DSPIN 10830 ON ANSN GOTO *MLOOPSUB, *MIDEXIT, *TESTSTART 10840 GOTO *MAINSTART 10850 *MLOOP SUB 10860 PS="0無変更、1時間間隔、23パパ、3パパパパ、4表示、5小 10870 -ドコピー、611-7、7計算" NK=7-LIFFRG:MC=5:GOSUB *DSPIN 10880 10890 ON ANSN GOSUB *MLP1, *MLP2, *MLP3, *MLP4, *MLP5, *MLP6, *MLP7 GOTO *MAINLOOP 10900 10910 10920 *TESTSTART 10930 PS="テスト実行ではデータエリアをクリアします宜しいですか (y:0, n:1)* 10940 NK-1:MC-5:GOSUB *DSPIN 10950 IF ANSN THEN *MAINLOOP 10960 TESTFRG=1:LPMINB=LPMIN:LPMIN=60:MAXN3B=MAXN3:MAXN3=0 10970 * 10980 '+++++ 実行 10990 11000 *MAINSTART 11010 GOSUB *LPPRMAKE 11020 LPN3-0 11030 IF TTTURNS=0 THEN PS="start = " ELSE PS="restart=" 11040 LOCATE 0,2:GOSUB *DSPTM 11050 ----- operation loop 11060 ' 11070 11080 *MIDLOOP IF TESTFRG=0 THEN MC=4:P\$="実行中" ELSE MC=6:P\$=" 11090 テスト 11100 GOSUB *DSPST LS=1:GOSUB *DSPREVS 11110 MC=5:PS="赤いボタンのSTOPスイッチで停止します 11120 . GOSUE *DSPM TWAIT\$ (0) = 6H0 : LPN% = MAXN% : LPN2=0 11130 11140 11150 ' +++++ assembla loop 11160 *LTLOOP 11170 IF TRNSFRG THEN CLOSE 12 11180 11190 STOP OFF 11200 DEF SEG-MSEG *LTLOOP1:CALL 11210 LAB* (TWAIT* (0), SEM* (0,0), D* (0,0,0,1), U* (0,0,0,1), D* (0,0,0, 0), U% (0, 0, 0, 0), RFDATA% (8*LBLFRG, 1), NRF%, LPN%) IF TWAITS (0) =0 AND MAXN2<>LPN2 THEN 11220 LPN2=LPN2+1:GOTO *LTLOOP1 11230 11240 * +++++ 11250 11260 *LTEXIT 11270 STOP ON IF TRNSFRG THEN OPEN "coml:n81nn" AS #2 GOSUB *DSPCLTG:GOSUB *DSPTITLE 11280 11290 MC=1:PS="処理中":BEEP:GOSUB *DSPST 11300 EFRG%-TWAIT% (0) AND SHFF 11310 IF MAXN& CLPN& AND EFRG& THEN 11320 LPI-LPN2*32767 +MAXN&-LPN% ELSE LPI-LPTURNI 11330 LPN3=LPN3+1:TTTURN:-TTTURN:+LP:DDATAS-DATES:TDATAS-TIMES 11340 IF MDRF-0 AND LIFFRG-0 THEN GOSUB *CHECKFREQ

10660 PS="設定を確認して下さい。(Y:0, N:1) "

11350 IF TESTFRG=1 THEN *LTERROR 11360 IF TRNSFRG THEN TRNSMODE -1: GOSUB *TRNSDATA ELSE 11370 GOSUB *RCONT 11380 11390 *LTERROR IF EFRG% AND &HIB THEN *MIDEXIT 11400 TE LPONEERGS O THEN *MIDEXIT 11410 IF INKEYS-CHRS(4H1B) THEN *MIDEXIT 11420 11430 ' 11440 GOTO *MIDLOOP 11450 11460 '+++++ stop operation 11470 ' 11480 *MIDEXIT 11490 IF (EFRG% AND &H19) =0 THEN *MIDEXIT2 11500 *MTDERROR 11510 IF EFRG* AND 4H8 THEN ERMSS=*RFコントロールエラー!* 11520 IF EFRG% AND &H1 THEN ERMSS=*PDPコントロールエラー! 11530 IF EFRG% AND GHIO THEN ERMSS="RFミスマッチ エラー!" 11540 BEEP 1:MC=2:PS="IJ-":GOSUB *DSPST:PRINT:PRINT ERMSS: 11550 PS="状態を確認後、何かキーを押して下さい。停止画面に入りま 11560 MC=2:GOSUB *DSPM 11570 *MIDE2:KS=INPUTS(1):IF KS=** THEN *MIDE2 11580 BEEP 0:COLOR 7 11590 11600 *MIDEXIT2 11610 GOSUB *DSPTITLE:MC-3:PS="存 止":GOSUB *DSPST 11620 IF TESTFRG THEN GOSUB *DSPCLT:GOSUB *DATNEW 11630 IF TESTERG THEN LPMIN-LPMINB:MAXN3-MAXN3B 11640 PS="ランの終了(0)、継続(1)、" 11650 IF HCFRG=0 THEN AS="ノー" ELSE AS="" 11660 PS=PS+AS+"ハードコピー (2で切替)、その他の処理(3) * 11670 NK=3:MC=5:GOSUB *DSPIN 11680 ON ANSN GOTO *MAINLOOP, *MIDEXIT3, *MIDLOOPSUB 11690 IF TESTFRG 1 THEN *MAINEXIT 11700 GOTO *MIDEXIT2 11710 *MIDEXIT3:HCFRG=(HCFRG+1) MOD 2:GOTO *MIDEXIT2 11720 11730 *MIDLOOPSUB PS="1プリント、2t-ブ、3再表示、4表示モード変更" 11740 11750 NK-6:MC-5:GOSUB *DSPIN 11760 ON ANSN GOSUB *PRNDATA, *SVRESULT, *MDLP3, *MLP4, *PRNPARA, *PRNSEM 11770 GOTO *MIDEXIT2 11780 ' 11790 '---- run stop 11800 11810 *MAINEXIT 11820 IF TRNSFRG THEN TRNSMODE =3: GOSUB *TRNSDATA: GOSUB *CPEFFECT 11830 MC=7:PS="アータのセーブ 中":GOSUB *DSPM 11840 GOSUB *SVRESULT 11850 IF TRNSFRG THEN *PSTOP 11860 MC=7:PS="アータのプリント中":GOSUB *DSPM 11870 GOSUB *PRNDATA 11880 11890 '+++++ selection 11900 11910 *PSTOP 11920 GOSUB *DSPTITLE:MC=7:PS="終 了":GOSUB *DSPST 11930 PS-*メニューへ (0)、新しいrunへ (1)、ハードコピー(2)、 停止へ戻る(3) * 11940 MC=7:GOSUB *DSPM 11950 *PSTOP2:ANSS=INKEYS:IF ANSS="" THEN LOCATE 70.0:PRINT TIMES:: GOTO *PSTOP2 11960 IF ANSS-"3" THEN *MIDEXIT 11970 IF ANSS="2" THEN GOSUB *CL3:GOSUB *PRNHCOPY:GOTO *PSTOP 11980 IF ANSS="1" THEN CONSOLE 0,25:GOSUB *CLO:GOTO *INIT 11990 IF ANSS-CHRS(&H1B) THEN FLNM15-"escdata":GOSUB *SVCONT1:STOP ON:STOP 12000 IF ANSS >"O" THEN BEEP: GOTO *PSTOP2 12010 12020 CONSOLE 0, 24, 1:COLOR 7 12030 VIEW (0,0) - (639, 399) : WINDOW (0,0) - (539, 399) : GOSUB 12040 STOP OFF

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12060 *ERNEND:RUN "MENU.BAS"
12070 END
12080
12090 '##### subroutine series #####
12100
12110 '---- menu
12120
12130 '---- selection
12140
12150 *SELMENU
12160 PS=*CPU1台モード(0) /データ転送モード(1)*
12170 MC=5:NK=1:GOSUB *DSPIN
12180 TRNSFRG-ANSN
12190 GOSUB *DSPMENU
12200 MFLNMS-FIMENUS (ANSN) :TITLES-NMMENUS (ANSN)
12210 RNMODE-MMENU (ANSN) :NSVDATA-NSVDATA (ANSN)
12220 PS=*通常モード(0)/微分データ同時表示モード(1)*
12230 MC=5:NK=1:GOSUB *DSPIN
12240 TE ANSN THEN RNMODE=RNMODE+1024:DSPMD%=2
12250 A*-RNMODE: GOSUB *FRGMAKE
12260 RETURN
12270
12280 '---- menu display
12290
12300 *DSPMENU
12310 GOSUB *DSPINIT
12320 RESTORE *MENUDATA
12330 READ NMENU
12340 FOR I=1 TO NMENU
12350 READ
CLMENU (I), CMNTS, FIMENUS (I), NMMENUS (I), MMENU (I), NSVDATA (I)
        COLOR CLMENU(I):LOCATE 0, I*2+1:PRINT I, CMNTS
12360
12370 NEXT I
12380 PS="作業内容を選択して下さい":MC=5:NK=NMENU:GOSUB
*DSPIN
12390 IF ANSN-0 THEN *ERNEND
12400 IF CLMENU (ANSN) =1 THEN *DSPMENU
12410 RETURN
12420 .
12430 *MENUDATA
12440 DATA 9
12450 DATA 6,"LifeTime测定", lifcntr, LifeTime, 16,0
12460 DATA 3, "2 A P 実行", 2apcntr, 2AP mode, 2,0
12470 DATA 3, " 4 A P 実行", 4apcntrt, 4AP (8/8), 6, 15
12480 DATA 3, " 8 A P 実行", 8apcntr, 8AP mode, 8, 3
12490 DATA 4, " 4 A P 実行 (rf on 8/rf
off8) ", 4apcntrd, 4AP (8/8), 2054,0
12500 DATA 3, * 8 A P (count 2, 2 Back Ground
4) ", 8apcntrt, 8AP (224), 72, 15
12510 DATA 7, * 8 A P (count 1, 2-Back Ground
3) ", 8apcntrb, 8AP (12-3), 136, 11
12520 DATA 3, " 2 A P (RFon+RFoff) ", 2apcntrb, RFon/off, 66, 15
12530 DATA 7, * 2 A P (RFon+RFoff-BG) *, 2apcntrb, doubleRF (-
BG),130,1
12540 '
12550 'RNMODE=ROBERG+AP2FRG*2+AP4FRG*4+AP8FRG*8
12560
RNMODE=RNMODE+LIFFRG*16+RF7FRG*32+PTSFRG*64+BGYFRG*128
12570
'RNMODE=RNMODE+DEXFRG*256+DAAFRG*512+cpdudfrg*1024+pslfrg*
2048
12580
12590 '---- parameters
12600
12610 *MLP1
12620 PS="何分間隔で途中経過を表示しますか (1-60)"
12630 MC-5: GOSUB *DSPM: INPUT ANSS
12640 ANSN-VAL (ANSS)
12650 IF ANSN>O AND ANSN<60 THEN LPMIN-ANSN ELSE
BEEP: GOTO *MLP1
12660 PS="表示何回毎に途中経過をプリントしますか (0:NO.n:
回数)"
12670 NK-9:MC-5:GOSUB *DSPIN
12680 MAXN3=ANSN
12690 RETURN
12700
12710 *MLP2
12720 MC-5:PS-*コメントを入れて下さい*:GOSUB *DSPM
12730 L1=23:C1=24:AS=RNCMNTS:GOSUB *DSPSIN:RNCMNTS=AS
12740 A=INSTR (AS, CHRS (6H22)) : IF A THEN RNCMNTS=LEFTS (AS, A-
```

12050 CLOSE

12750 RETURN 12760 12770 *MLP4 12780 PS="表示モードの選択(0:通常/1:上下/2:左右/3:二 画面) = 12790 NK=3:MC=5:GOSUB *DSPIN 12800 DSPMD&=ANSN 12810 IF ANSN<1 OR ANSN>2 THEN *MLP41 12820 PS=*オートスケール 個別(0)/同一(1)* 12830 NK-1:MC-5:GOSUB *DSPIN 12840 DSPSCFRG-ANSN 12850 *MLP41 12860 IF ANSN>O AND ANSN<3 THEN RETURN 12870 P5="表示チャンネルの選択 (0:1、2CH/1:3、4CH) * 12880 NK=1:MC=5:GOSUB *DSPIN 12890 DSPCH*=ANSN 12900 RETURN 12910 ' 12920 *MLP5 12930 PS="ハードコピーモードの選択 (0:OFF/1:ON) * 12940 NK-1:MC-5:GOSUB *DSPIN 12950 HCFRG-ANSN 12960 RETURN 12970 12980 *MLP6 12990 PS="SINGLE LOOP モードの選択 (0:OFF/1:ON) " 13000 NK-1:MC-5:GOSUB *DSPIN 13010 LPONEFRGS-ANSN 13020 RETURN 13030 13040 *MT.P3 13050 PS="データエリアをクリアします宜しいですか (yes:0, n 0:1) -13060 NK-1:MC-5:GOSUB *DSPIN 13070 IF ANSN=0 THEN GOSUB *DATNEW 13080 RETURN 13090 13100 *MLP7 13110 PS="On resonance点の指定 (0:maximum) 13120 MC-5:GOSUB *DSPM:INPUT ANS\$:ANSN-VAL(ANS\$) 13130 IF ANSN>0 AND ANSN<NRF% THEN SP1-ANSN ELSE BEEP : GOTO *MLP7 13140 PS="off resonance点の指定(0:off周波数の 点) " 13150 MC-5:GOSUB *DSPM: INPUT ANSS: ANSN-VAL (ANSS) 13160 IF ANSN>O AND ANSN<NRF% THEN SP2=ANSN ELSE BEEP:GOTO *MLP7 13170 RETURN 13180 ' 13190 '---- redisplay 13200 13210 *MDLP3 13220 GOSUB *CPEFFECT: GOSUB *DSPCLT: GOSUB *DSPCONT: GOSUB *DSPEFFECT:RETURN 13230 13240 '------ display temprary data and save 13250 13260 *RCONT 13270 GOSUB *SVCONT:GOSUB *CPEFFECT:GOSUB *DSPCONT 13280 IF LPN3>-MAXN3 AND MAXN3<>0 THEN GOSUB *PRNDATA:LPN3=0 13290 RETURN 13300 13310 '---- key input 13320 13330 *IKEY 13340 ANSS-INKEYS 13350 LOCATE 70, 0: PRINT TIMES; 13360 IF ANSS-"" THEN *IKEY 13370 IF ANSS-CHRS(4H1B) THEN BEEP 0:GOTO *PSTOP 13380 IF ANSS<"O" OR ANSS>CHRS(4H30+NK) THEN BEEP:GOTO IKEY 13390 ANSN-VAL(ANSS) 13400 LOCATE 70,0:PRINT SPACES(9); 13410 RETURN 13420 ' 13430 '---- initialize 13440 ' 13450 '---- GPIB 13460 '

1) :GOTO *MLP2

13470 *INITGP:RETURN 13480 13490 *GPTRG: RETURN 13500 13510 *GPLCL: RETURN 13520 13530 *CHECKFREQ 13540 GOSUB *INITGP:GOSUB *GPTRG:GOSUB *GPICL: GS=MTDS (GS. 10. CKL) 13550 IF CHECKRFS<>GS AND (EFRG% AND 6) =0 THEN EFRG%=EFRG%+6H10 13560 RETURN 13570 13580 *INITGPE 13590 13600 '==== assembla load 13610 ' 13620 *LDMPRG 13630 DEF SEG-MSEG 13640 IF LBLFRG THEN BS="1b1\" ELSE BS="vdg\" 13650 BLOAD SYDRIVES+BS+MFLNMS+".m" 13660 *LDMPRG2 13670 DEF SEG-MSEG2 13680 BLOAD SYDRIVES+"hcbaslc.bin" 13690 RETURN 13700 13710 '---- data output 13720 ' 13730 *TRNSDATA 13740 PS="モニタプログラムが未準備です。確認してください" 13750 MC=2:NK=1:BEEP 1:GOSUB *DSPM 13760 WRITE #2, *START* 13770 BEEP 0:GOSUB *CL3:FOR I=0 TO 600:NEXT I 13780 IF LOC(2)>1 THEN *TRNSDATA1 13790 PS="モニタブログラムが未準備です。確認後" 0"を押してくだ さい 13800 MC-2:NK-1:BEEP 1:GOSUB *DSPIN 13810 IF LOC(2)>1 THEN AS-INPUTS(LOC(2), #2) 13820 BEEP 0:GOTO *TRNSDATA 13830 *TRNSDATA1 13840 INPUT #2,A5 13850 IF A\$<>"OK" THEN *TRNSERROR 13860 WRITE #2, TRNSMODE% 13870 ON TRNSMODE% GOSUB *TRNS1, *TRNS2, *TRNS3 13880 WRITE #2, "ENT" 13890 INPUT #2,A\$ 13900 IF ASO"END" THEN *TRNSERROR 13910 BEEP 0 13920 RETURN 13930 ' 13940 *TRNSERROR 13950 RETURN 13960 13970 *TRNS1 13980 GOSUB *SEND1:GOSUB *SEND2 13990 RETURN 14000 14010 *TRNS2 14020 GOSUB *SEND2 14030 RETURN 14040 14050 *TRNS3 14060 RETURN 14070 14080 *SEND1 14090 WRITE #2, RNMODE, NRF%, NSVDATA, NCH, MAXN3 14100 FOR I-0 TO 15 14110 WRITE #2, TWAIT& (I), PARA (I) 14120 NEXT I 14130 FOR I-1 TO NRES 14140 WRITE 14140 WHIL \$2, RFDATA\$(0, I), RFDATA\$(1, I), RFDATA\$(2, I), RFDATA\$(3, I), RFD ATA\$(4, I), RFDATA\$(5, I), RFDATA\$(6, I), RFDATA\$(7, I) 14150 NEXT I 14160 WRITE #2, LPN3, DSPMD*, DSPCH*, HCFRG, SP1, SP2, DSPSCFRG 14170 WRITE 12, TITLES, RNMS 14180 WRITE #2, RNCMNTS 14190 RETURN 14200 14210 *SEND2 14220 WRITE 12, EFRG&, TTTURN 14230 WRITE #2, TDATAS 14240 FOR I-0 TO 15

#1, RSEC(0, I, K), RERSEC(0, I, K), RSEC(1, I, K), RERSEC(1, I, K), RSE 14250 WRITE #2, SEM# (0, I), SEM# (1, I) C(2, I, K), RERSEC(2, I, K), RSEC(3, I, K), RERSEC(3, I, K) 14260 NEXT I 14270 FOR L=0 TO NCH-1 14980 NEXT T 14990 NEXT K FOR I=1 TO NRF% FOR J=0 TO NSVDATA 14280 15000 *ERNSVR12:CLOSE #1 15010 FLNMS=DTDRIVES+*\asc\"+"A"+RIGHTS(RNMS, LEN(RNMS) -14290 14300 WRITE 1) +" .DAT" \$2, U% (O, J, I, L), U% (1, J, I, L), D% (O, J, I, L), D% (1, J, I, L) 15020 *ERNSVR2: OPEN FLNMS FOR OUTPUT AS #1:WRITE 14310 NEXT J NEXT I A1 NRES NSUDATA NCH 14320 15030 FOR K=0 TO NCH 14330 NEXT L FOR I=1 TO NRF% 15040 14340 RETURN 14350 ' 15050 FOR J=0 TO NSVDATA *ERNSVR21:WRITE 15060 14360 '---- save #1, NU# (I), UP# (J, I, K), DW# (J, I, K) 14370 . 15070 NEXT J 14380 '---- faile check 15080 NEXT I 14390 ' 15090 NEXT K 14400 *FILECHECK 15100 *ERNSVR22:WRITE #1, RNCMNTS:FOR I=0 TO 31:WRITE 14410 ANSN-0: OPEN FLNMS FOR INPUT AS #1 #1, PARA (I) :NEXT 14420 PS="すでに同じランNO. があります。統行しますか (Y:0/ 15110 FOR I-O TO 15:WRITE #1, SEM% (O, I), SEM% (1, I):NEXT 15120 CLOSE #1 N:1) -14430 CLOSE #1:BEEP 1:NK=1:MC=6:GOSUB *DSPIN:BEEP 0 15130 RETURN 14440 CS="変更する" 14450 *FILECHECK2:CLOSE #1 15140 ' 15150 '---- load 14460 RETURN 15160 ' 14470 ' 15170 '---- continuous from temporary data 14480 '---- check disk space 15180 ' 14490 ' 15190 *LDOLD 14500 *DISKCHECK 15200 GOSUB *CL3:AS=DTDRIVES+"\TMP\"+RNMS+".*":GOSUB 14510 MC=2:GOSUB *DISKCHECK1 *DSPFILE 14520 RETURN 15210 AS=LEFTS (AS, LEN (AS) -1):BS="":CS="継続する実験データの 14530 *DISKCHECK1: IF DSKF (DTDRIVES) <10000 THEN GOSUB *:GOSUB *INPFILE 15220 *ERNLDOLD:OPEN FLNMS FOR INPUT AS #1 *TRAP32 14540 RETURN 15230 FOR I-0 TO 15 14550 *DISKCHECK2: IF DSKF (DTDRIVE) <10 THEN GOSUB *TRAP32 15240 INPUT #1, I, TWAIT* (I), PARA (I) 15250 NEXT I 14560 RETURN 14570 15260 P= (RNMODE-PARA(15)) + (NSVDATA-PARA(14)) * 4096:MC=2 15270 IF P THEN CLOSE:PS="Runモードが異なり継続できません! *:BEEP:GOSUB *DSPM:GOTO *LDDATA 14580 '---- temporary results 14590 14600 *SVCONT 15280 FOR I=0 TO 15 14610 EL=0:GOSUB *DISKCHECK 15290 INPUT #1, I, SEM*(0, I), SEM*(1, I) 15300 NEXT I 14620 TS=TIMES:GOSUB *PRDTMAKE1 14630 15310 FLNM1 \$=RNM\$+"."+CHR\$ (65+VAL (MID\$ (T\$, 1, 2)))+MID\$ (T\$, 4, 2) 15320 FOR I-1 TO PARA(0) 14640 *SVCONT1 14650 FLNMS=DTDRIVES+"\TMP\"+FLNM1S INPUT 15330 #1, RFDATA%(0, I), RFDATA%(1, I), RFDATA%(2, I), RFDATA%(3, I), RFD ATA%(4, I), RFDATA%(5, I), RFDATA%(6, I), RFDATA%(7, I) 15340 FOR J=0 TO NSVDATA 14660 *ERNSVC:OPEN FLNMS FOR OUTPUT AS #1 14670 FOR I=0 TO 15 14680 WRITE #1,I,TWAIT%(I),PARA(I) 15350 INPUT 14690 NEXT I 14700 FOR I-0 TO 15 1, U\$ (0, J, I, 0), U\$ (1, J, I, 0), D\$ (0, J, I, 0), D\$ (1, J, I, 0), U\$ (0, J, I, 1), U\$ (1, J, I, 1), D\$ (0, J, I, 1), D\$ (1, J, I, 1) WRITE #1, I, SEM% (0, I), SEM% (1, I) 14710 15360 NEXT J 15370 NEXT I 14720 NEXT I 14730 15380 INPUT #1, RNCMNTS 14740 FOR I=1 TO NRF% 15390 CLOSE #1 14750 WRITE 15400 GOSUB *NUDTMAKE \$1, RFDATA* (0, I), RFDATA* (1, I), RFDATA* (2, I), RFDATA* (3, I), RFD 15410 RNMS-LEFTS (RNMS, 8) : LOCATE 50, 0: PRINT RNMS ATA* (4, I), RFDATA* (5, I), RFDATA* (6, I), RFDATA* (7, I) 15420 RETURN 14760 FOR J-O TO NSVDATA 15430 14770 WRITE 15440 '---- continuous of parameters \$1, U% (0, J, I, 0), U% (1, J, I, 0), D% (0, J, I, 0), D% (1, J, I, 0), U% (0, J, 15450 ' I, 1), U% (1, J, I, 1), D% (0, J, I, 1), D% (1, J, I, 1) 14780 NEXT J 15460 *LDCNT 15470 IF NRF%=0 THEN RETURN *LDDATA 15480 FLNMS=DTDRIVES+*\RESULT\"+RNMS+".dat" 14790 NEXT I 14800 WRITE #1, RNCMNTS 14810 CLOSE #1 15490 GOSUB *FILECHECK 15500 ON ANSN GOTO *LDDATA 14820 RETURN 15510 GOSUB *DATNEW 14830 15520 RETURN 14840 '---- final results 15530 14850 ' 15540 '---- read parameter file 14860 *SVRESULT 15550 14870 EL-1:GOSUB *DISKCHECK 15560 *LDNEW 14880 AS-DTDRIVES+"\RESULT\":BS=".DAT":FLNMS=AS+RNMS+BS 15570 FLNMS-DTDRIVES+"\RESULT\"+RNMS+".dat" 14890 GOSUB *FILECHECK 15580 GOSUB *FILECHECK 14900 ON ANSN GOSUB *INPFILE 15590 ON ANSN GOTO *LDDATA 14910 *ERNSVR1: OPEN FLNMS FOR OUTPUT AS #1:WRITE #1, NRF* 15600 14920 FOR K-O TO NCH 15610 *LDNEW1 AS="ch"+STRS(K)+" Freq(Hz) U/D (error) Effect 14930 15620 TTTURN =0 (error) " 15630 IF LIFFRG<>0 THEN FS="\WTLF\" ELSE FS="\WAIT\" 14940 FOR I-1 TO NRFS 15640 GOSUB *CL3:AS=PRDRIVES+FS+"*.DAT":GOSUB *DSPFILE *ERNSVR11:WRITE #1, RNCMNTS:WRITE #1, AS 14950 15650 AS=LEFTS (AS, LEN (AS) -5) :BS=" .DAT" 14960 WRITE 15660 CS="タイムシークエンスデータの":GOSUB *INPFILE 1,NU(I),UD(I,K),ER(I,K),EFFECT(I,K),EFFERR(I,K) 14970 IF AP8FRG THEN WRITE #1,"R1 R2 R3 R4":WRITE 15670 *ERNLDNEW1: OPEN FLNMS FOR INPUT AS #1

15700 INPUT #1,X,Y,Z TWAIT*(X) -Y 15720 IF X=0 THEN BMTIME=Z 15730 15740 IF X=1 THEN RFTIME=Z IF X=2 THEN CTTIME=Z IF X=3 THEN BMCLTIME=2 15750 15760 IF X=4 THEN RFCUTTIME=Z IF X=5 THEN CTTIME2=Z 15780 IF X=6 THEN CTTIME3=Z 15790 NEXT I 15800 INPUT #1, TMCMNTS 15810 CLOSE #1 15820 15830 *LDNEW2 15840 IF LIFFRG>0 THEN FS="LF" ELSE FS="RF" 15850 GOSUB *CL3:AS=PRDRIVES+"\"+FS+"*.DAT":GOSUB *DSPFILE 15860 AS=LEFTS (AS, LEN (AS) -5):BS=".DAT" 15870 CS="マッピングする "+FS+" データの":GOSUB *INPFILE 15880 *ERNLDNEW2:OPEN FLNMS FOR INPUT AS #1 15890 INPUT #1,N 15900 NRF%-N 15910 FOR I-1 TO N INPUT \$1,X,Y\$,Z\$ IF X-0 THEN GOSUB *LDNEW4 ELSE GOSUB *LDNEW3 15920 15930 15940 NEXT I 15950 INPUT #1, RNCMNTS 15960 CLOSE #1 15970 ' 15980 PS-**しばらく御待ち下さい**MC-5:GOSUB *DSPM 15990 RNCMNTS-TMCMNTS+RNCMNTS 16000 IF LIFFRG >0 THEN FOR I-1 TO CTURN:NU+(I) =CTTIME * I:NEXT I:NRF*=CTURN 16010 GOSUB *RFDTMAKE 16020 GOSUB *DATNEW 16030 RETURN 16040 16050 *LDNEW3 16060 NU# (X) =Y# 16070 RFDA* (0, X) = INT (2#/10000) : RFDA* (1, X) = 2#-RFDA* (0, X) *10000 16080 RETURN 16090 16100 *LDNEW4 16110 NRF%-NRF%-1 16120 IF Y -0. THEN OFRF-2. 16130 IF Y -1. THEN MDRF-2. 16140 IF Y -2. THEN SFTRF-Z. 16150 IF Y1-34 THEN CTURN-Z1 16160 RETURN 16170 16180 '---- making of parameter data 16190 16200 '---- calculation of one cycle time 16210 16220 *PARAMAKE1 16230 A=BMTIME+BMCLTIME+(AP8FRG*2+AP4FRG+1)*(RFTIME+RFCUTTIME) 16240 B=(A+CTTIME+AP8FRG*CTTIME2+BGYFRG*CTTIME3)*(1+AP8FRG) 16250 IF PSLFRG THEN CYCTIME=B*2 ELSE CYCTIME=B*NRF% 16260 IF LIFFRG THEN CYCTIME=B+CTTIME*NRF% 16270 CYCTIME-CYCTIME/1000 16280 IF LIFFRG-0 AND LBLFRG<>0 THEN CYCTIME= (AP8FRG+1) *BMCYC*NRF* 16290 IF LIFFRG >0 AND LBLFRG <>0 THEN CYCTIME=BMCYC 16300 RETURN 16310 ' 16320 '---- making of file name 16330 16340 *PARAMAKE2 16350 IF CPDUDFRG THEN TITLES=TITLES+"(dUD_mode)" 16360 IF TRNSFRG THEN TITLES=TITLES+"(trs_mode)" 16370 TITLES-LEFTS (TITLES, 28) 16380 PRTITLES-TITLES 16390 RETURN 16400 ' 16410 '---- calculation of loop number 16420

15680 INPUT #1,N

16430 *LPPRMAKE

16440 MAXN= (LPMIN*60-BSTIME) /CYCTIME

15690 FOR I=1 TO N

16450 LI-LPMIN*60:CI-CYCTIME:LPTURNI-LI/CI:IF LPTURNI<1 THEN LPTURN#=1 16460 IF LPTURN#>32767 THEN MAXN2-INT(LPTURN#/32767):MAXN*=LPTURN#-MAXN2*32767 ELSE MAXN2-0:MAXN*=INT(LPTURN#) 16470 LPTURN#-MAXN2*32767#+MAXN* 16480 RETURN 16490 ' 16500 '---- making of flags on experimental mode 16510 . 16520 *FRGMAKE 16530 IF A* AND 4H800 THEN PSLFRG=1 ELSE PSLFRG=0 16540 IF A* AND 4H400 THEN CPDUDFRG=1 ELSE CPDUDFRG=0 16550 IF A& AND 4H200 THEN DAAFRG=1 ELSE DAAFRG=0 16560 IF A* AND 4H100 THEN DEXFRG-1 ELSE DEXFRG-0 16570 IF A* AND 4H80 THEN BGYFRG-1 ELSE BGYFRG-0 16580 IF A* AND 4H40 THEN PTSFRG=1 ELSE PTSFRG=0 16590 IF A* AND 4H20 THEN RF7FRG=1 ELSE RF7FRG=0 16600 IF At AND 4H10 THEN LIFFRG=1 ELSE LIFFRG=0 THEN AP8FRG=1 ELSE AP8FRG=0 THEN AP4FRG=1 ELSE AP4FRG=0 16610 IF A& AND 4H8 16620 IF A* AND 4H4 16630 IF A* AND 6H2 THEN AP2FRG=1 ELSE AP2FRG=0 16640 IF AN AND 4H1 THEN ROBFRG=1 ELSE ROBFRG=0 16650 RETURN 16660 16670 '---- making of rf data and parameters 16680 16690 *RFDTMAKE 16700 FOR I=1 TO NRF% 16710 GOSUB *BTODATA:GOSUB *TRODATA 16720 NEXT I 16730 *PRDTMAKE 16740 PARA(0) =NRF*: PARA(1) =BMTIME: PARA(2) =RFTIME: PARA(3) =CTTIME: PARA (4) -OFRF 16750 PARA (5) =MDRF: PARA (6) =SFTRF: PARA (7) =CYCTIME: PARA (8) =RFCUTTI 16760 PARA (9) -CTTIME2:PARA (10) -CTTIME3:PARA (11) -BMCLTIME 16770 PARA (14) -NSVDATA:PARA (15) -RNMODE 16780 *PRDTMAKE1 16790 IF TTTURN#>32767 THEN PARA(13) -INT (TTTURN#/32767) ELSE PARA (13) =0 16800 PARA (12) -TTTURN -PARA (13) *32767 16810 RETURN 16820 ' 16830 *BTODATA 16840 RFDATA*(0, I) =I 16850 RFDATA*(1, I) =RFDA*(0, I) 16860 RFDATA* (2, I) = RFDA* (1, I) 16870 AS=MIDS (AS, 2, L) 16880 RFGPS(I) ="?A"+CHRS(6H24)+"FR"+STR\$(NU#(I)/1E+06)+"MH"+CHRS (6HD)+CHRS(6HA) 16890 A*-VARPTR (RFGP\$ (I), 0) : B*-VARPTR (RFGP\$ (I), 1) : DEF SEG-B* 16900 "RFDATA* (3, I) =VAL (* 6H"+HEX\$ (PEEK (A*+3)) +HEX\$ (PEEK (A*+2))) 16910 A=VAL (*6H"+HEX\$ (PEEK (A*+2)) +HEX\$ (PEEK (A*+1))) 16920 IF A>32767 THEN RFDATA* (3, I) =A-65536! ELSE RFDATA* (3, I) =A 16930 A-VAL("\$\#"+HEXS(PEEK(A*+4))+HEXS(PEEK(A*+3))) 16940 IF A>32767 THEN RFDATA*(4,I)=A-65536! ELSE RFDATA* (4, I) =A 16950 REDATA* (5, I) -PEEK (A*) 16960 'IF PEEK (A*+1) <>0 THEN RFDATA* (4, I) -SEGPTR (5) ELSE RFDATA* (4, I) = B* 16970 RFDATA*(7, I) = INT (NU# (I) /32768!) : RFDATA*(6, I) = NU# (I) = RFDATA\$ (7, I) *32768! 16980 RETURN 16990 ' 17000 *TRODATA 17010 AS-STRS (NU# (I)) 17020 L-LEN (AS) -1 17030 AS-MIDS (AS, 2, L) 17040 L=9-LEN (AS) 17050 B\$=STRINGS (L, "0") +AS 17060 FOR J=0 TO 7 17070 RFDATA*(J+8,I)=VAL(MIDS(BS,J+1,1)) 17080 NEXT J 17090 RETURN 17100 17110 *NUDTMAKE

17120 TTTURN#=32767#*PARA(13) +PARA(12) 17130 *NUDTMAKE1 17140 NRF%-PARA(0):BMTIME-PARA(1):RFTIME-PARA(2):CTTIME-PARA(3): OFRF-PARA(4) 17150 MDRF-PARA (5) : SFTRF-PARA (6) : CYCTIME-PARA (7) : RFCUTTIME-PARA (17160 CTTIME2=PARA(9):CTTIME3=PARA(10):BMCLTIME=PARA(11) 17170 FOR I=1 TO NRF* 17180 GOSUB *BTDATA:GOSUB *TRODATA 17190 NEXT I 17200 RETURN 17210 ' 17220 *BTDATA 17230 NU#(I)=RFDATA*(7,I)*32768!+RFDATA*(6,I) 17240 RETURN 17250 ' 17260 *TRDATA 17270 NU# (I) =0 17280 FOR J=8 TO 15 17290 NU#(I)=NU#(I)+RFDATA%(J,I)*10#^(8-J) 17300 NEXT J 17310 RETURN 17320 17330 '---- making of rf check data 17340 ' 17350 *CKRFMAKE 17360 CKL-LEN (STR\$ (NU# (NRF%)))-2 17370 A#=NU# (NRF%) *1E+16 17380 B\$=STR\$ (A#) 17390 CHECKRFS-MIDS (BS, 2, CKL) 17400 RETURN 17410 ' 17420 '---- initialize of rf data 17430 ' 17440 *DATNEW 17450 FOR I=0 TO NCH+CPDUDFRG 17460 FOR J=0 TO NRF% FOR K=0 TO NSVDATA 17470 17480 U% (0, K, J, I) -0:D% (0, K, J, I) -0 17490 U% (1, K, J, I) =0:D% (1, K, J, I) =0 17500 NEXT K 17510 NEXT J 17520 NEXT I 17530 TTTURN#-0:SEM#-0:FOR I-0 TO 15:SEM#(0,I)-0:SEM#(1,I)-0:NEXT I 17540 RETURN 17550 ' 17560 '----- file name 17570 ' 17580 *RNMMAKE 17590 DS=DATES 17600 BS-STRS (VAL (MIDS (DS, 2, 1)) -5) +HEXS (VAL (MIDS (DS, 4, 2))) +MIDS (DS, 7, 2) 17610 IF RNMS↔ ** THEN CS=STRS (VAL (MIDS (RNMS, 6, 3)) +1) ELSE CS="000" 17620 CS=RIGHTS("00"+RIGHTS(CS, LEN(CS)-1),3) 17630 RNMS="S"+MIDS(BS,2,4)+CS 17640 RETURN 17650 ' 17660 '---- input file name 17670 ' 17680 *INPFILE 17690 PS-CS+*ファイル名を入力してください(*+BS+*)* 17700 MC-5:GOSUB *DSPM:COLOR 4:INPUT ANSS 17710 IF ANSS="P" OR ANSS="p" THEN GOSUB *PRFILE:GOTO *INPFILE 17720 FLNMS=AS+ANSS+BS 17730 RETURN 17740 ' 17750 '---- display 17760 ' 17770 '---- display effects 17780 17790 *DSPEFFECT 17800 IF LIFFRG⇔0 THEN GOSUB *DSPEFFECTL ELSE GOSUB *DSPEFFECTP 17810 TTTIME=TTTURN # * CYCTIME: TTMIN=INT (TTTIME/60) : TTSEC=INT (TTTI ME-TTMIN* 60) 17820 LOCATE 0,2:COLOR 5:PRINT TDATAS+" ("+STRS (TTMIN)+"'"+STRS (TTSEC)+"'') ";

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SEM="+STRS (A) +" "
17840 PRINT CHRS (6H22) + LEFTS (RNCMNTS, 40) + CHRS (6H22) ;
17850 RETURN
 17860 '
 17870 *DSPEFFECTE
17880 LOCATE 10,19+K:COLOR EFFCL(K)
17890 EFFMSGS=AKCNVS (STR$ (EFFECTM (K) )) +* ±
"+AKCNVS(STRS(EFFERR#(K)))+"$ "
17900 PRINT "effect ("+STRS(P1)+"/"+STRS(P2)+")
 ="+EFFMSGS+SPACES(10);
 17910 RETURN
17920 '
17930 *DSPEFFECTI
 17940 LOCATE 10,18+K:COLOR 4+K
17950 EFFMSGS-AKCNVS (STRS (TTUP # (K) )) +" /
"+AKCNVS (STRS (TTDW# (K) )) +" count"
 17960 PRINT "total UP/DOWN"+EFFMSGS+SPACES (10);
17970 RETURN
17980
17990 '---- display parameters
18000 '
18010 *DSPSET
 18020 GOSUB *DSPSET1:GOSUB *DSPSET2
18030 RETURN
18040 '
 18050 *DSPSET1
18060 LOCATE 0,4:COLOR 4:PRINT"パラメータ設定";
18070 LOCATE 0,16:COLOR 4:PRINT"ビームタイム";:COLOR
6:PRINT BMTIME;:COLOR 4:PRINT" E - A # 4 A";:COLOR
6:PRINT BMTIME;:COLOR 4:PRINT" (m s e c) ";
18080 LOCATE 0,17:COLOR 4:PRINT" E - A # - JV";:COLOR
6:PRINT BMCLTIME
18090 RT=RFTIME+BMTIME*ROBFRG
 18100 IF LIFFRG=0 THEN LOCATE 0,17:COLOR 4:PRINT" R F 94
 A";:COLOR 6:PRINT RT;
 18110 IF AP4FRG-1 THEN COLOR 4:PRINT" × 2"
          IF AP8FRG=1 THEN COLOR 4:PRINT" × 3"
 18120
 18130 IF LIFFRG=0 THEN LOCATE 0, 18:COLOR 4:PRINT" R F CUT #
 1 4 ";: COLOR 6: PRINT RECUTTIME;
18140 LOCATE 0,20:COLOR 4:PRINT カウント ";:COLOR
6:PRINT CTTIME
 18150 IF AP8FRG<>0 THEN LOCATE 10,19:COLOR 4:PRINT"前
 ";:COLOR 6:PRINT CTTIME2;
18160 IF BGYFRG<>0 THEN LOCATE 10,21:COLOR 4:PRINT"後
";COLOR 6:PRINT CTTIME3;
18170 IF LIFFRG<>0 THEN PS="タイム マップ (sec) = ELSE
PS="RF マップ (kHz) =
 18180 LOCATE 0,7:COLOR 4:PRINT PS;
 18190 LOCATE 40,7:COLOR 4:PRINT "点数 ";:COLOR 6:PRINT
 NRF %
18200 RETURN
 18210
 18220 *DSPSET2
18230 FOR I-1 TO NRF%
          X(I) = (NU#(I) + SFTRF) /10
 18240
 18250
           OFX=OFRF/10
           MDX-MDRF/10
 18260
 18270 NEXT I
18280 N-NRF%
18290 IF OFX-0 THEN OFX-1E+08
 18300 VIEW (0,160)-(639,240)
 18310 GOSUB *CPWX
 18320 WY1=30:WY2=215:MDY=150:DMDY=5:TY=90:BY=210
18330 WINDOW (WX1,-WY2)-(WX2,-WY1)
18340 LINE (TX,-MDY)-(01X,-MDY),1:LINE (02X,-MDY)-(BX,-
 MDY),5
18350 DSPOFFRG- (AP2FRG OR ROBFRG OR AP4FRG OR AP8FRG)
18360 IF LIFFRG<>0 THEN XAXISS="sec" ELSE XAXISS="kHz"
 18370 GOSUB *DSPXAXIS
18380 OFN=0:DMDY2=DMDY*5
18390 FOR I=1 TO NRF%
          IF X(I) >= OFX THEN GOSUB *DSPSET23 ELSE GOSUB
 18400
*DSPSET22
18410 DMDY2=DMDY2*-1
18420 NEXT I
18430 IF DSPOFFRG=1 THEN GOSUB *DSPSET24
18440 RETURN
 18450 '
18460 *DSPSET22
18470 LINE (X(I)+MDX,-MDY+DMDY*5+DMDY2)-(X(I)-MDX,-MDY-
 DMDY*5+DMDY2),2,8
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17830 A-SEM#: B-TTTURN#: PRINT "Loop="+STR\$ (B) +"

18490 RETURN 18500 18510 *DSPSET23 18520 LINE (OX, -MDY+DMDY*5+DMDY2) - (OX, -MDY-DMDY*5+DMDY2), 6:OFN=OFN+1 18530 RETURN 18540 ' 18550 *DSPSET24 18560 LOCATE 55,7:COLOR 4:PRINT " (内off"; 18570 COLOR 6:PRINT STRS (OFN) ; :COLOR 4:PRINT ") " 18580 RETURN 18590 ' -- display temporary data 18600 18610 18620 *DSPCONT 18630 VIEW (0,32)-(639,367) 18640 N=NRF% 18650 IF DSPMD%=0 THEN T=0 ELSE T=1 18660 DSPSC2FRG=(DSPSCFRG AND T) 18670 C1-DSPCH%:IF CPDUDFRG THEN C2-2 ELSE C2-(DSPCH%+1) MOD NCH 18680 IF DSPSC2FRG THEN GOSUB *DSPCONTSUB2 18690 FOR IK-0 TO T K= (IK+DSPCH*) MOD NCH 18700 IF IK AND DSPDUDFRG THEN K-NCH GOSUB *DSPCONTSUB:GOSUB *DSPEFFECT 18710 18720 18730 NEXT IK 18740 DSPSTMD*=DSPMD* 18750 RETURN 18760 . 18770 *DSPCONTSUB 18780 FOR I=1 TO N X(I) = (NU#(I) +SFTRF)/10 OFX=OFRF/10 18790 18800 18810 MDX=MDRF/10 18820 Y(I) -UD(I,K) Z(I) =ER(I,K) 18830 18840 2C(I) =ERC(I, K) IF LIFFRG >0 THEN IF ERC(I, K) =0 THEN ZC(I) =7-K 18850 ELSE ZC(I)=3 18860 NEXT I 18870 P1-P1 (K) : P2-P2 (K) : DSPOFRG-AP8FRG 18880 DSPOFFRG= (AP2FRG OR ROBFRG OR AP4FRG) 18890 IF OFX=0 THEN OFX=1E+08 18900 IF LIFFRG<>0 THEN XAXISS="sec" ELSE XAXISS="kHz" 18910 IF APBFRG<0 THEN YAXISS="(8AP)" ELSE YAXISS="(U/D)" 18920 IF LIFFRG<0 THEN YAXISS="count" 18930 IF LIFFRG >0 THEN DSPLOGFRG=1:SCAT2FRG=1 ELSE DSPLOGFRG=0:SCAT2FRG=0 18940 GOSUB *DSPMODE:GOSUB *CL5 18950 GOSUB *CPWX 18950 GOSUB "CPWX 18960 IF DSPSC2FRG=0 THEN GOSUB "CPWY 18970 IF LIFFRG<>0 THEN IDY=1 18980 GOSUB *DSPPACK 18990 RETURN 19000 19010 *DSPCONTSUB2 19020 FOR I=1 TO N Y (I) -UD (I, C1) 19030 19040 Z(I) -ER(I,C1) 19050 NEXT I 19060 FOR I-1 TO N 19070 Y(I+N)=UD(I,C2) 19080 Z(I+N)=ER(I,C2) 19090 NEXT I 19070 19080 19100 DSPOFRG-AP8FRG 19110 N=2*N:GOSUB *CPWY:N=N/2 19120 IF LIFFRG >0 THEN IDY-1 19130 RETURN 19140 19150 '---- display messeges 19160 ' 19170 '---- initialize of screen 19180 ' 19190 *DSPINIT 19200 COLOR 7 :WIDTH 80,25 19210 SCREEN 3,0,0,1 19220 VIEW (0, 32) - (639, 367) 19230 CONSOLE 23, 2, 0, 1 19240 GOSUB *CL5 19250 RETURN

18480 LINE (X(I), -MDY+DMDY*.6+DMDY2) - (X(I), -MDY-

DMDY*.6+DMDY2),6,8

19260 ' 19270 '---- change scroll 19280 19290 *DSPCLT 19300 CONSOLE 2,21:CLS 1:CONSOLE 23,2 19310 RETURN 19320 . 19330 19340 ' 19350 *DSPCT.TG 19360 CONSOLE 2,21:GOSUB *CLO:CONSOLE 23,2 19370 RETURN 19380 . 19390 '---- display waiting 19400 ' 19410 *DSPWAITMES 19420 GOSUB *DSPCLTG:COLOR MC:LOCATE 28,11:PRINT *LIIS < 御待ち下さい**: 19430 RETURN 19440 ' 19450 '---- display file name 19460 ' 19470 *DSPTITLE 19480 GOSUB *CL2:COLOR 5:LOCATE 0,0:PRINT TITLES; 19490 LOCATE 40,0:PRINT "実験名=";:COLOR 6:LOCATE 50,0:PRINT RNMS; :COLOR 7 19500 RETURN 19510 19520 '---- display message 19530 19540 *DSPM 19550 GOSUB *CL3:LOCATE 0, 23:COLOR MC:PRINT PS; 19560 RETURN 19570 ' 19580 '---- display conditions 19590 ' 19600 *DSPST 19610 LOCATE 0,1:COLOR MC:PRINT PS+STRINGS(73,61); 19620 RETURN 19630 1 19640 '---- display questions 19650 ' 19660 *DSPIN 19670 GOSUB *DSPM:GOSUB *IKEY:GOSUB *CL3:COLOR 7 19680 RETURN 19690 ' 19700 '---19710 . 19720 *DSPSIN 19730 LOCATE C1, L1:COLOR 6:PRINT AS 19740 LOCATE C1-2, L1:COLOR 5:INPUT BS 19750 IF BS<>"" THEN AS-BS 19760 RETURN 19770 19780 '---- display time 19790 19800 *DSPTM 19810 LOCATE 0,2:COLOR 5:PRINT PS+TIMES+" +CHR\$ (&H22) +RNCMNT\$+CHR\$ (&H22); 19820 RETURN 19830 19840 '---- graph package 19850 19860 '---- display file name 19870 19880 *DSPFILE 19890 GOSUB *DSPCLT:LOCATE 0, 2:COLOR 4:FILES AS:COLOR 7 19900 RETURN 19910 19920 '---- erase texts and graphics 19930 19940 *CLO:GOSUB *CL4:GOSUB *CL5:RETURN 19950 19960 '---- erase upper text 19970 19980 *CL2:LSCROLL=2:LOCATE 0, 0:PRINT SPACES (LSCROLL*80-1) ; : RETURN 19990 ' 20000 '---- erase lower text 20010 20020 *CL3:LSCROLL=2:LOCATE 0,23:PRINT SPACES (LSCROLL*80-1) ; : RETURN 20030

20040 '---- erase all text 20050 20060 *CL4:CLS 1:GOSUB *CL2:GOSUB *CL3:RETURN 20070 20080 '---- erase graphics 20090 ' 20100 *CL5:CLS 2:RETURN 20110 20120 '---- character reverse 20130 20140 *DSPREVS 20150 IF DSPREV* THEN RETURN ELSE DEF SEG=4HA200:DSPREV*=1 20160 A=LS*160:FOR I=A TO A+156 STEP 2:B=PEEK(I)+2:POKE I, B:NEXT I 20170 RETURN 20180 ' 20190 '---- cancel reverse 20200 20210 *DSPNOMR 20220 IF DSPREV& THEN DEF SEG-4HA200:DSPREV&=0 ELSE DSPREV4=0 20230 A=LS*160:FOR I=A TO A+156 STEP 2:B=PEEK(I)-2:POKE I, B:NEXT I 20240 RETURN 20250 ' 20260 '---- display characters 20270 20280 *GRACHR 20290 LL-LEN (SS\$) : SXX-MAP (XXX, 0) : SYY-MAP (YYY, 1) 20300 FOR I-1 TO LL CCS= (MIDS (SSS, I, 1)) 20310 20320 PUTS (SXX+8*(I-1), SYY), KANJI (ASC(CCS)), PSET, COL, 0 20330 NEXT I 20340 RETURN 20350 ' 20360 '---- set display mode 20370 20380 *DSPMODE 20390 ON DSPMD& GOTO *DSPMODE1, *DSPMODE2, *DSPMODE3, *DSPMODE4 20400 *DSPMODE0 20410 VIEW (0,48)-(639,367) 20420 RETURN 20430 *DSPMODE1 20440 IF K THEN VIEW (0,200)-(639,367) ELSE VIEW (0,48)-(639,199) 20450 RETURN 20460 *DSPMODE2 20470 IF K THEN VIEW (320,48)-(639,367) ELSE VIEW (0,48)-(319,367) 20480 RETURN 20490 *DSPMODE3 20500 A= (K+DSPCH%) MOD 2 20510 IF A THEN SCREEN 3,0,1,17 20520 VIEW (0,48)-(639,367) 20530 RETURN 20540 *DSPMODE4 20550 VIEW (0,0) - (639,399) 20560 RETURN 20570 ' 20580 '---- calculation of x-axis 20590 ' 20600 *CPWX 20610 WINDOW(0,0)-(1,1):WDXSZ-MAP(1,0) 20620 MAXX-0:MINX-3E+08 20630 FOR I=1 TO N IF MAXX<X(I) AND X(I)<OFX THEN MAXX-X(I) IF MINX>X(I) THEN MINX-X(I) 20640 20650 20660 NEXT I 20670 MAXX-MAXX+MDX:MINX-MINX-MDX 20680 DX-MAXX-MINX 20690 IF DX=0 THEN DX=1:MINX=MINX-.5:MAXX=MAXX+.5 20700 TX=MINX-DX*.1:BX=MAXX+DX*.15:DMDX=DX*.02 20710 0X=BX-DX*.05:01X=BX-DX*.13:02X=BX-DX*.08 20720 WX2=BX+DX*.05:WX1=(WDXSZ*(TX-DMDX)-8*6*WX2)/(WDXSZ-8*6) 20730 D=DX*1000:GOSUB *CPDIV:DX=D/1000:IDX=ID/1000:IDX2=ID2/1000 20740 RETURN 20750 20760 '---- calculation of y-axis 20770 ' 20780 *CPWY

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20790 WINDOW(0,0)-(1,1):WDYSZ=MAP(1,1)
 20800 MAXY=0:MINY=1E+08
 20810 IF SCAT2FRG THEN GOSUB *CPWY2 ELSE GOSUB *CPWY1
 20820 IF DSPOFRG AND MAXY<0 THEN MAXY=0
20830 IF DSPOFRG AND MINY>0 THEN MINY=0
 20840 DY-MAXY-MINY
 20850 IF DY=0 THEN DY=1:MINY=MINY-.5:MAXY=MAXY+.5
 20860 TY-MINY-DY*.1:BY-MAXY+DY*.1:DMDY-DY*.05
20870 WY2-BY+DY*.05:WY1=(-WY2*16+(TY-DMDY)*WDYSZ)/(WDYSZ-
 16)
 20880 D=DY*100:GOSUB
 *CPDIV:DY=D/100:IDY=ID/100:IDY2=ID2/100
 20890 RETURN
 20900
 20910 *CPWY1
 20920 FOR I=1 TO N
20930 IF MAXY<Y(I)+Z(I) THEN MAXY=Y(I)+Z(I)
          IF MINY>Y(I)-Z(I) THEN MINY-Y(I)-Z(I)
 20940
 20950 NEXT T
 20960 RETURN
 20970 .
 20980 *CPWY2
 20990 FOR I=1 TO N
 21000
           IF MAXY<Y(I) THEN MAXY=Y(I)
 21010
           IF MINY>Y(I) THEN MINY=Y(I)
 21020
            IF MAXY<Z(I) THEN MAXY=Z(I)
 21030 IF MINY>Z(I) THEN MINY=Z(I)
21040 NEXT I
 21050 RETURN
 21060 '
 21070
        '---- calculation of ticks
 21080 .
 21090 *CPDTV
 21100 C=0
 21110 FOR I=1 TO 10
         IF INT (D/10^ (C+1)) <>0 THEN C=C+1
 21120
 21130 NEXT I
 21140 A-INT (D/10°C)
21150 IF A>-2 AND A<4 THEN ID-5*10°(C-1):ID2-1*10°(C-1)
 21160 IF A>=4 AND A<8 THEN ID=1*10°C:ID2=.2*10°C
 21170 IF A>=8 THEN ID=2*10^C: ID2=.5*10^C
 21180 IF A<2 THEN ID=2*10* (C-1) : ID2=.5*10* (C-1)
 21190 RETURN
 21200 .
21210 '---- display graph
 21220
21230 *DSPPACK
 21240 WINDOW (0,0)-(1,1):WDXSZ-MAP(1,0):WDYSZ-MAP(1,1)
21250 WINDOW (WX1,-WY2)-(WX2,-WY1)
21260 XXX-WX1:YYY--WY2:SSS=YAXISS:COL=7:GOSUB *GRACHR
 21270 XXX-MAP (WDXSZ-3*8, 2) : YYY-MAP (WDYSZ-
 16*1, 3):SSS=XAXISS:COL=7:GOSUB *GRACHR
 21280 LINE (TX, -TY) - (BX, -BY), 4, B
21290 IF DSPORRG THEN LINE (TX,-0)-(BX,-0),3
21300 GOSUB *DSPXAXIS
21310 GOSUB *DSPYAXIS
21320 GOSUB *DSPSCAT
21330 RETURN
21340
21350 '---- display x-axis
21360
21370 *DSPXAXIS
21380 T-INT (320/WDXSZ)
21390 ITX-INT (TX/IDX) *IDX+IDX:IBX-INT (O1X/IDX) *IDX
21400 IF IBX-ITX THEN IBX-ITX+IDX
21410 T0=-TY:T1=-TY+DMDY:T2=-TY+DMDY*.5
21420 B0=-BY:B1=-BY-DMDY:B2=-BY-DMDY*.5
21430 ITX2-ITX-IDX
21440 IF ITX2<0 THEN ITX2=0
21450 GOSUB *DSPXSUBAXIS
21460 FOR IX-ITX TO IBX STEP IDX
          LINE (IX,TO)-(IX,TI),4:LINE (IX,BO)-(IX,BI),4
IF T<>1 THEN ISMB-IX/100:GOSUB *DSPXSMBAXIS
21470
21480
           T=T*-1
21490
          ITX2-IX
GOSUB *DSPXSUBAXIS
21500
21510
21520 NEXT IX
21530 IF DSPOFFRG THEN GOSUB .DSPOFF
21540 RETURN
21550
21560 *DSPXSUBAXIS
21570 FOR IX2-ITX2 TO ITX2+IDX STEP IDX2
21580 IF IX2<TX OR IX2>01X THEN C=0 ELSE C=4
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21610 RETURN 21620 ' 21630 *DSPXSMBAXIS 21640 AS=STRS (ISMB) :L=LEN (AS) -1 21650 IF L>6 THEN L-6 21660 XXX=IX-DX*.033:YYY--TY+DMDY:SSS-MIDS (AS, 2, L) :COL=7:GOSUB *GRACHR 21670 RETURN 21680 1 21690 *DSPOFF 21700 LINE (01X, T0) - (02X, T0), 0:LINE (01X, B0) - (02X, B0), 0 21710 AS-STRS (OFX/100):L-LEN(AS)-1 21720 XXX-01X-50:YYY--TY+DMDY:SSS-MIDS(AS,2,L):COL-5:GOSUB *GRACHR 21730 LINE (OX, T0) - (OX, T1), 4: LINE (OX, B0) - (OX, B1), 4 21740 RETURN 21750 ' 21760 '--- display y-axis 21770 . 21780 *DSPYAXTS 21790 T-INT (184/WDYSZ) 21800 ITY-INT (TY/IDY)*IDY+IDY:IBY=INT (BY/IDY)*IDY 21810 IF IBY=ITY THEN IBY-ITY+IDY 21820 T1-TX-DMDX:T2-TX-DMDX*.5:B1-BX+DMDX:B2=BX+DMDX*.5 21830 ITY2-ITY-1 21840 IF DSPLOGFRG THEN GOSUB *DSPYSUBAXISL ELSE GOSUB *DSPYSUBAXIS 21850 FOR IY-ITY TO IBY STEP IDY LINE (T1,-IY)-(TX,-IY),4:LINE (B1,-IY)-(BX,-IY),4 IF T<>1 THEN ISMB-IY:GOSUB *DSPYSMBAXIS 21860 21870 21880 T=T*-1 21890 ITY2-IY 21900 IF DSPLOGFRG THEN GOSUB *DSPYSUBAXISL ELSE GOSUB *DSPYSUBAXIS 21910 NEXT IY 21920 RETURN 21930 21940 *DSPYSUBAXIS 21950 FOR IY2-ITY2 TO ITY2+IDY STEP IDY2 21960 IY3-IY2 21970 IF IY3<TY OR IY3>BY THEN *DSPYSUBAXIS2 21980 LINE (T2,-IY3)-(TX,-IY3),4:LINE (B2,-IY3)-(BX,-IY3),4 21990 *DSPYSUBAXIS2:NEXT IY2 22000 RETURN 22010 . 22020 *DSPYSUBAXISL 22030 FOR IY2-10^ITY2 TO 10^ (ITY2+IDY) STEP 10^ITY2 22040 IY3-LOG (IY2) /LOG (10) 22050 IF IY3<TY OR IY3>BY THEN *DSPYSUBAXISL2 LINE (T2,-IY3)-(TX,-IY3),4:LINE (B2,-IY3)-(BX,-22060 IY3).4 22070 *DSPYSUBAXISL2:NEXT IY2 22080 RETURN 22090 ' 22100 *DSPYSMBAXIS 22110 IF DSPLOGFRG THEN BS="10^":NL=3 ELSE BS="":NL=6 22120 AS=STR\$ (ISMB):L-LEN (AS)-1:XXX-WX1:YYY=-IY-DMDY*.5 22130 IF INSTR (AS, "E-") THEN AS=" 0.0":L=3 22140 IF L>NL THEN L-NL 22150 IF -YYY>WY1 AND -YYY<WY2 THEN SSS-BS+MIDS(AS,2,L):COL=7:GOSUB *GRACHR 22160 RETURN 22170 22180 '--- SCAT 22190 ' 22200 *DSPSCAT 22210 DMX-DX*.004:DMY-DY*.01:DOFX-.2 22220 IF SCAT2FRG THEN GOSUB *DSPSCATON2 ELSE GOSUB DSPSCATONI 22230 IF LIFFRG-0 THEN GOSUB *DSPCALPOINT 22240 RETURN 22250 22260 *DSPCALPOINT 22270 IF P1 THEN LINE (X(P1) + DMX, -Y(P1) - DMY) - (X(P1) - DMX, -Y (P1) +DMY) , 2, BF 22280 IF P2 THEN LINE (X(P2)+DMX, -Y(P2)-DMY)-(X(P2)-DMX,-Y (P2) + DMY), 5, B 22290 RETURN 22300 . 22310 *DSPSCATON1

21590 LINE (IX2,T0)-(IX2,T2),C:LINE (IX2,B0)-(IX2,B2),C 22320 FOR I-1 TO N 22330 IF X(I)>-OFX THEN GOSUB *DSPSCATOFF:GOTO *DSPSCATON11 LINE (X(I)+MDX,-Y(I))-(X(I)-MDX,-Y(I)), ZC(I) LINE (X(I),-Y(I)-Z(I))-(X(I),-Y(I)+Z(I)), ZC(I) LINE (X(I)+DMX,-Y(I)-DMY)-(X(I)-DMX,-22340 22350 22360 Y(I) +DMY) . ZC(I) LINE (X(I) + DMX, -Y(I) + DMY) - (X(I) - DMX, -Y(I) -22370 DMY), 2C (I) 22380 *DSPSCATON11 22390 NEXT I 22400 RETURN 22410 22420 *DSPSCATON2 22430 FOR I-1 TO N 22440 IF X(I)>=OFX THEN GOSUB *DSPSCATOFF:GOTO *DSPSCATON21 LINE (X(I)+DMX,-Z(I))-(X(I)-DMX,-Z(I)), ZC(I)-2 LINE (X(I),-Z(I)-DMY)-(X(I),-Z(I)+DMY), ZC(I)-2 LINE (X(I)+DMX,-Y(I)-DMY)-(X(I)-DMX,-22450 22460 22470 Y(I) + DMY) . ZC(I) 22480 LINE (X(I)+DMX,-Y(I)+DMY)-(X(I)-DMX,-Y(I)-DMY) . ZC (I) 22490 *DSPSCATON21 22500 NEXT I 22510 RETURN 22520 22530 *DSPSCATOFF 22540 A3=02X+IDX2*DOFX 22550 LINE (A3, -Y(I) -Z(I)) - (A3, -Y(I) +Z(I)), 4 22560 A1=A3-MDX:IF A1<02X THEN A1=02X-DMX 22570 A2=A3+MDX:IF A2>BX THEN A2=BX 22580 A4-A3+DMX: A5-A3-DMX 22590 LINE (A1, -Y(I)) - (A2, -Y(I)), 4 22600 IF P2=0 THEN C=5 ELSE C=7 22610 LINE (A4, -Y (I) +DMY) - (A5, -Y (I) -DMY), C 22620 LINE (A4, -Y(I) -DMY) - (A5, -Y(I) +DMY), C 22630 DOFX-DOFX+.4 22640 RETURN 22650 22660 '---- printer output 22670 1 22680 *PRNDATA 22690 TTTIME-TTTURN * CYCTIME: TTMIN-INT (TTTIME/60) : TTSEC-INT (TTTI ME-TTMIN*60) 22700 IF HCFRG THEN GOSUB *PRNHCOPY 22710 IF NCH-2 THEN A-2 ELSE A-0 22720 IF CPDUDFRG THEN A-NCH 22730 A=LIFFRG*A 22740 FOR KC-0 TO A 22750 GOSUB *PRNLIST 22760 NEXT KC 22770 RETURN 22780 22790 *PRNHCOPY 22800 I=-1:GOSUB *PRNTITLE 22810 DEF SEG-MSEG2: IF HCFRG-2 THEN A-3 ELSE A-6 22820 CALL A 22830 'GOSUB *FF 22840 RETURN 22850 22860 *PRNLIST 22870 IF APSFRG THEN N-2 ELSE N-40 \ (NSVDATA+1) 22880 PAGE=(NRF%-1) \ N 22890 FOR I-O TO PAGEE 22900 GOSUB *PRNTITLE IF LIFFRG THEN GOSUB *PRNTITLEL ELSE GOSUB 22910 *PRNTITLEP IF I-PAGEE THEN MAXJ-NRF%-I*N ELSE MAXJ-N 22920 22930 FOR J=1 TO MAXJ 22940 K=T*N+.T NUR -NU (K) +SFTRF 22950 IF LIFFRG THEN GOSUB *PRNDATAL ELSE GOSUB 22960 *PRNDATAP IF (J MOD 5) -0 THEN LPRINT 22970 22980 NEXT J 22990 GOSUB *FF:NEXT I 23000 RETURN 23010 ' 23020 *PRNTITLE 23030 LPRINT PRTITLES, RNMS, DDATAS+" "+TDATAS+" page"+STRS (PAGEE*KC+I+1) : LPRINT

23040 LPRINT "set"+STR\$ (KC) +" +CHR\$ (6H22) +RNCMNT\$+CHR\$ (6H22) : LPRINT 23050 LPRINT USING "COUNT ### #; NRF*; 23060 LPRINT USING "total time - **** 分 ** 秒 TTMIN. TTSEC: 23070 LPRINT "SEM - ", SEM#: LPRINT 23080 P25="total count UP (chi) - + + + + + + + / DOWN (ch##) -******** 23090 LPRINT USING P25;1,TTUP*(0),2,TTDW*(0) 23100 LPRINT USING P25; 3, TTUP# (1) , 4, TTDW# (1) 23110 RETURN 23120 23130 *PRNTITLEL 23140 P1S=" T(ms) UP1-2 DOWN1-2" UP1 DOWN1 UP2 DOWN2 23150 225-******** ******* ******* ******** 23160 LPRINT: LPRINT: LPRINT P15: LPRINT 23170 RETURN 23180 ' 23190 *PRNDATAL 23200 LPRINT USING P25;NUR#,UP#(0,K,0),DW#(0,K,0),UP#(0,K,1),DW#(0,K,1),UP#(0 , K, 2) , DW# (0, K, 2) 23210 RETURN 23220 23230 *PRNTITLEP 23250 LPRINT USING P2\$; P1 (KC) , P2 (KC) , EFFECTM (KC) , EFFERRM (KC) , MDRF 23260 P1\$="Freq.(Hz) UP DOWN U/D error +\$\$\$.\$\$\$\$ (\$\$\$.\$\$\$\$)" 23280 LPRINT: LPRINT PIS: LPRINT 23290 RETURN 23300 23310 *PRNDATAP 23320 IF NSVDATA THEN GOSUB *PRNDATA1 ELSE GOSUB *PRNDATAO 23330 RETURN 23340 23350 *PRNDATAO 23360 L=0:LPRINT USING P2S; NUR#, UP# (L, K, KC), DW# (L, K, KC), UD (K, KC), ER (K, KC), EFFECT (K, KC) , EFFERR (K, KC) 23370 RETURN 23380 23390 *PRNDATA1 23400 P25-"######## ####### ######## +###.#### (###.####)" 23410 LPRINT USING P2S; NUR . UP . (0, K, KC) , DW . (0, K, KC) , R (0, K, KC) , RER (0, K, KC) 23420 FOR L-1 TO NSVDATA LPRINT USING 23430 P25; L+1, UP # (L, K, KC), DW # (L, K, KC), R (L, K, KC), RER (L, K, KC) 23440 NEXT L 23450 P25=" +\$\$\$. \$\$\$\$ (\$\$\$. \$\$\$\$) +***. **** (***. ****)* 23460 LPRINT USING P25; UD (K, KC), ER (K, KC), EFFECT (K, KC), EFFERR (K, KC) 23470 IF AP8FRG THEN *PRN8AP 23480 RETURN 23490 23500 *PRN8AP 23510 LPRINT 23520 225-Rseci -23530 FOR M-0 TO 3 LPRINT USING P25; M+1, RSEC (M, K, KC) , RERSEC (M, K, KC) 23540 23550 NEXT M 23560 LPRINT 23590 M=3:N=2:GOSUB *PRN8AP2 23600 M=0:N=2:GOSUB *PRN8AP2 23610 M-3:N-1:GOSUB *PRN8AP2 23620 P25= BAP = +\$\$\$. \$\$\$\$ (\$\$\$. \$\$\$\$)%" 23630 LPRINT USING P2S; UD (K, KC), ER (K, KC) 23640 LPRINT "

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23650 RETURN
23660 '
23670 *PRN8AP2
23680 R-RSEC (M, K, KC) /RSEC (N, K, KC)
23690
E=R*SQR ( (RERSEC (M, K, KC) /RSEC (M, K, KC) ) *2+ (RERSEC (N, K, KC) /RS
EC (N, K, KC) ) ^2)
23700 LPRINT USING P25; M+1, N+1, (R-1) *100, E*100
23710 RETURN
23720 '
23730 '---- beam current
23740 '
23750 *PRNSEM
23760 LPRINT PRTITLES, RNMS, DATES+" "+TIMES: LPRINT
23770 LPRINT CHRS (6H22) +RNCMNTS+CHRS (6H22) : LPRINT
23780 LPRINT "------ SEM CHECK --
23790 LPRINT " order low
                                        high"
23800 P25- "
                    10*+** ****** ******
23810 FOR I=0 TO 15
23820 IF LBLFRG THEN A=I-2 ELSE A=I
         LPRINT USING P2S; A, SEM& (0, I), SEM& (1, I)
23830
23840 NEXT I
23850 GOSUB *FF
23860 RETURN
23870
23880 '---- parameter values
23890 '
23900 *PRNPARA
23910 LPRINT PRTITLES, RNMS, DATES+" "+TIMES:LPRINT
23920 LPRINT CHR$ (6H22) +RNCMNTS+CHR$ (6H22) : LPRINT
23930 LPRINT "----- PARAMETER CHECK -
TWAITS"
23950 P25= *
23960 FOR I=0 TO 31
23970
       LPRINT USING P25; I, PARA (I) , TWAIT% (I)
23980 NEXT I
23990 GOSUB *FF
24000 RETURN
24010 '
24020
       '---- form feed
24030 .
24040 *FF
24050 AS="LPT1:"
24060 OPEN AS FOR OUTPUT AS #1
24070 PRINT #1, CHR$ (6HC) ;
24080 CLOSE #1
24090 RETURN
24100
24110 *PRNEND
24120
24130 '---- calculation of effects
24140
24150 *CPEFFECT
24160 IF TRNSFRG-O THEN IF CPDUDFRG THEN GOSUB *CPDUDUD
ELSE IF NCH>1 THEN GOSUB *CPSUBUD
24170 FOR K-O TO NCH-TRNSFRG
       TTUP# (K) =0:TTDW# (K) =0
A=LIFFRG+AP2FRG*2+AP8FRG*3
24180
24190
24200
         ON A GOSUB *CPEFFECTL, *CPEFFECT2AP, *CPEFFECT8AP
24210 NEXT K
24220 GOSUB *CPSEM
24230 RETURN
24240 '
24250 *CPEFFECTL
24260 FOR J-1 TO NRF%
24270
         ERC (J, K) =0
24280
             GOSUB .CPUD
24290
         IF A THEN UD (J, K) -LOG (UP : (0, J, K) ) / LOG (10) ELSE
24300
UD (J.K) =0
24310 R(0, J, K) -UD (J, K)
24320 IF B THEN ER (J, K) -LOG (DW# (0, J, K)) /LOG (10) ELSE
ER (J, K) -0
24330
       RER (0, J, K) =ER (J, K)
24340 NEXT J
24350 RETURN
24360
24370 *CPEFFECT2AP
24380 UDOFF=0:EROFF=0:NUD=0:MAXEFF=0:UDOFF2=0:EROFF2=0
24390 CPMODE=PTSFRG+BGYFRG*2+1
24400 FOR J-NRF& TO 1 STEP -1
        FOR L=0 TO NSVDATA
24410
24420
            GOSUB *CPUD
```

24440 RERSUM-0 ON CPMODE GOSUB *CPRSECO, *CPRSEC2, *CPRSEC4 24450 L=0:GOSUB *CPRSEC 24460 UD (J, K) =RSEC (0, J, K) 24470 ER (J, K) =UD (J, K) * SQR (RERSUM) IF (NU# (J) +SFTRF) >=OFRF THEN GOSUB *CPUDOFF 24480 24490 IF NUD-0 THEN GOSUB *CPUDOFF2 24500 24510 NEXT J 24520 IF NUD-0 THEN UDOFF-UDOFF2:EROFF=EROFF2 24530 UDOFF-UDOFF/EROFF: EROFF=1/SQR (EROFF) 24540 FOR J=1 TO NRF% 24550 IF (NU# (J) +SFTRF)>=OFRF THEN ERC (J, K) =7:GOTO *CPEFFECT2APOFF GOSUB *CPEFFECT2 IF ABS(EFFECT(J,K))>=MAXEFF THEN 24560 24570 MAXEFF=ABS (EFFECT (J, K)) : MAXEFFNO=J 24580 *CPEFFECT2APOFF 24590 NEXT J 24600 GOSUB *CPEFFECTM 24610 RETURN 24620 24630 *CPEFFECT8AP 24640 UDOFF=0:EROFF=0:NUD=0:MAXEFF=0:UDOFF2=0:EROFF2=0 24650 CPMODE=PTSFRG+BGYFRG*2+1 24660 FOR J=1 TO NRF% FOR L=0 TO NSVDATA 24670 GOSUB *CPUD 24680 NEXT L 24690 24700 RERSUM-0 ON CPMODE GOSUB *CPRSEC1, *CPRSEC3, *CPRSEC5 24710 24720 UD (J, K) =RSEC (0, J, K) *RSEC (3, J, K) /RSEC (1, J, K) /RSEC (2, J, K) -1 24730 ER (J, K) = (UD (J, K) +1) *SQR (RERSUM) 24740 NEXT J 24750 FOR J=1 TO NRF% 24760 IF (NU# (J)+SFTRF)>=OFRF THEN ERC (J, K)=7:GOTO *CPEFFECT8APOFF 24770 EFFECT (J, K) =UD (J, K) *100: EFFERR (J, K) =ER (J, K) *100 IF ABS (EFFECT (J, K)) >-MAXEFF THEN MAXEFF-ABS (EFFECT (J, K)) : MAXEFFNO-J S=INT (ABS (EFFECT (J, K) / EFFERR (J, K))) 24790 IF S>2 THEN ERC(J, K) =2 ELSE ERC(J, K) =4+S 24800 24810 *CPEFFECT8APOFF:UD(J,K)=UD(J,K)*100:ER(J,K)=ER(J,K)*100 24820 NEXT J 24830 IF SP1=0 THEN P1(K) -MAXEFFNO ELSE P1(K) -SP1 24840 EFFECTM (K) =UD (P1 (K) , K) : EFFERRM (K) =ER (P1 (K) , K) : EFFCL (K) =ERC (P1(K),K) 24850 RETURN 24860 ' 24870 '----- calculation of beam current in LBL 24880 ' 24890 *CPSEM 24900 SEM#=0 24910 IF LBLFRG THEN A-2 ELSE A-0 24920 FOR I-0 TO 15 24930 SEM#=SEM#+ (SEM# (1, I) *32768!+SEM# (0, I)) *10#^ (I-A) 24940 NEXT I 24950 RETURN 24960 ' 24970 '---- calculation of counts and ratios 24980 ' 24990 *CPUD 25000 UP\$(L,J,K)=U%(1,L,J,K)*32768!+U%(0,L,J,K) 25010 DW\$(L,J,K)=D%(1,L,J,K)*32768!+D%(0,L,J,K) TTUP (K) -TTUP (K) +UP (L, J, K) : TTDW (K) -TTDW (K) +DW (L, J, K) 25030 IF UP (L, J, K) <- 0 THEN CH-1:UP (L, J, K) -0:GOSUB *ERCP:A=0 ELSE A=-1 25040 IF DW#(L,J,K)<=0 THEN CH=2:DW#(L,J,K)=0:GOSUB *ERCP:B=0 ELSE B-1 25050 IF A AND B THEN GOSUB *CPR 25060 RETURN 25070 ' 25080 *CPR 25090 R(L, J, K) -UP+ (L, J, K) /DW+ (L, J, K) 25100 RER(L, J, K) = R(L, J, K) * SQR(1!/UP+(L, J, K)+1!/DW+(L, J, K)) ERUPSECI-SOR (UPSECI+(A2+1) *UPB2I) : ERDWSECI-SOR (DWSECI+(A2+ 25110 RETURN 1) *DWB2 () :GOSUB *CPRSEC 25120

25130 '---- calculation of ratios in each section

24430

NEXT L

25150 *CPRSEC 25160 IF UPSECI <1 OR DWSECI <1 THEN UPSEC -1: DWSEC -1: ERUPSEC -1: ERDWSEC -1 25170 RSEC(L, J, K) -UPSEC / DWSEC 25180 RERSEC (L, J, K) =RSEC (L, J, K) *SQR ((ERUPSEC#/UPSEC#) *2+ (ERDWSEC #/DWSEC#) ^2) 25190 RERSUM-RERSEC (L, J, K) /RSEC (L, J, K) *RERSEC (L, J, K) /RSEC (L, J, K) +RERSUM 25200 RETURN 25210 25220 *CPRSEC0 25230 UPSEC#-UP# (0, J, K) :DWSEC#-DW# (0, J, K) 25240 ERUPSECI-SQR (UPSECI) : ERDWSECI-SQR (DWSECI) 25250 RETURN 25260 25270 *CPRSEC1 25280 FOR L-0 TO 3 UPSECI-UPI (L, J, K) : DWSECI-DWI (L, J, K) 25290 ERUPSECI-SQR (UPSECI) :ERDWSECI-SQR (DWSECI) GOSUB *CPRSEC 25300 25310 25320 NEXT L 25330 RETURN 25340 25350 *CPRSEC2 25360 UPSEC#=0:DWSEC#=0 25370 FOR M=0 TO 3 25380 UPSEC#=UP# (L*4+M, J, K) +UPSEC#:DWSEC#=DW# (L*4+M, J, K) +DWSEC# 25390 NEXT M 25400 ERUPSECI-SQR (UPSECI) : ERDWSECI-SQR (DWSECI) 25410 RETURN 25420 25430 *CPRSEC3 25440 L=0:UPSEC#=UP# (0, J, K) +UP# (1, J, K) :DWSEC#=DW# (0, J, K) +DW# (1, J 25450 ERUPSECI-SQR (UPSECI) : ERDWSECI-SQR (DWSECI) : GOSUB *CPRSEC 25460 L=1:UPSEC#=UP# (2, J, K) +UP# (3, J, K) :DWSEC#=DW# (2, J, K) +DW# (3, J 25470 ERUPSEC -SQR (UPSEC) : ERDWSEC -SQR (DWSEC) : GOSUB *CPRSEC 25480 L=2:UPSEC#=UP# (8, J, K) +UP# (9, J, K) :DWSEC#=DW# (8, J, K) +DW# (9, J 25490 ERUPSECI-SQR (UPSECI) : ERDWSECI-SQR (DWSECI) : GOSUB *CPRSEC 25500 L=3:UPSEC#=UP# (10, J, K) +UP# (11, J, K) :DWSEC#=DW# (10, J, K) +DW# (11, J, K) 25510 ERUPSECI-SQR (UPSECI) : ERDWSECI-SQR (DWSECI) : GOSUB *CPRSEC 25520 RETURN 25530 25540 *CPRSEC4 25550 UPSEC#=UP#(0, J, K) -UP#(1, J, K) *CTTIME/CTTIME3 25560 ERUPSEC#=SQR(UP#(0, J, K) +UP#(1, J, K)) 25570 DWSEC -DW# (0, J, K) -DW# (1, J, K) *CTTIME/CTTIME3 25580 ERDWSECI-SQR (DW# (0, J, K) +DW# (1, J, K)) 25590 RETURN 25600 25610 *CPRSECS 25620 A1-CTTIME2/CTTIME3:A2-CTTIME/CTTIME3 25630 UPB#-UP# (3, J, K) +UP# (4, J, K) +UP# (5, J, K) :UPB1#-A1*UPB#:UPB2#-A2*UPB# 25640 DW8#-DW# (3, J, K) +DW# (4, J, K) +DW# (5, J, K) :DW81#-A1*DW8#:DW82#-A2*DWB 25650 L=0:UPSEC#=UP# (0, J, K) -UPB1#:DWSEC#=DW# (0, J, K) -DWB1# 25660 ERUPSEC = SQR (UPSEC + (A1+1) *UPB1 +) : ERDWSEC = SQR (DWSEC + (A1+ 1) *DWB1 () : GOSUB *CPRSEC 25670 L-1: UPSEC - UP + (1, J, K) + UP + (2, J, K) -UPB2#: DWSEC = DW# (1, J, K) + DW# (2, J, K) - DWB2#

UPB#-UP# (9, J, K) +UP# (10, J, K) +UP# (11, J, K) :UPB1#-A1*UPB#:UPB2 #=A2*UPB# 25700 DWB#=DW# (9, J, K) +DW# (10, J, K) +DW# (11, J, K) :DWB1#=A1*DWB#:DWB2 #=A2*DWB# 25710 L=2:UPSEC#=UP# (6, J, K) -UPB1#:DWSEC#=DW# (6, J, K) -DWB1# 25720 ERUPSEC#=SQR (UPSEC#+(A1+1)*UPB1#) : ERDWSEC#=SQR (DWSEC#+(A1+ 1) *DWB1() : GOSUB *CPRSEC 25730 L=3:UPSEC#-UP# (7, J, K) +UP# (8, J, K) -UPB2#:DWSEC#=DW# (7, J, K) +DW# (8, J, K) -DWB2# 25740 ERUPSEC#=SQR (UPSEC#+ (A2+1) *UPB2#) : ERDWSEC#=SQR (DWSEC#+ (A2+ 1) *DWB2#) :GOSUB *CPRSEC 25750 RETURN 25760 25770 '---- calculaiton of time devided data 25780 25790 *CPDUDUD 25800 FOR J=1 TO NRF% FOR L=O TO NSVDATA 25810 U\$ (0, L, J, NCH) =U\$ (0, L, J, 0) -U\$ (0, L, J, NCH+1) D\$ (0, L, J, NCH) =D\$ (0, L, J, 0) -D\$ (0, L, J, NCH+1) 25820 25830 U% (0, L, J, NCH+1) =U% (0, L, J, 0) 25840 25850 D% (0, L, J, NCH+1) =D% (0, L, J, 0) U% (1, L, J, NCH) =U% (1, L, J, 0) -U% (1, L, J, NCH+1) 25860 D% (1, L, J, NCH) =D% (1, L, J, 0) -D% (1, L, J, NCH+1) 25870 U% (1, L, J, NCH+1) =U% (1, L, J, 0) D% (1, L, J, NCH+1) =D% (1, L, J, 0) 25880 25890 25900 NEXT L 25910 NEXT J 25920 RETURN 25930 ' 25940 *CPDUDCLR 25950 FOR J=1 TO NRF% FOR L=0 TO NSVDATA U%(0, L, J, NCH+1) =0:D%(0, L, J, NCH+1) =0 25960 25970 25980 U% (1, L, J, NCH+1) =0:D% (1, L, J, NCH+1) =0 25990 NEXT L 26000 NEXT J 26010 RETURN 26020 . 26030 '---- calculation of chl - ch2 26040 ' 26050 *CPSUBUD 26060 FOR J=1 TO NRF% FOR L-O TO NSVDATA 26070 U% (0, L, J, NCH) =U% (0, L, J, 0) -U% (0, L, J, 1) 26080 D* (0, L, J, NCH) =D* (0, L, J, 0) -D* (0, L, J, 1) 26090 U% (1, L, J, NCH) =U% (1, L, J, 0) -U% (1, L, J, 1) 26100 D% (1, L, J, NCH) =D% (1, L, J, 0) -D% (1, L, J, 1) 26110 26120 NEXT L 26130 NEXT J 26140 RETURN 26150 . 26160 '---- calculation of off level 26170 . 26180 *CPUDOFF2 26190 UDOFF2-UDOFF2+UD (J, K) /ER (J, K) /ER (J, K) 26200 EROFF2-EROFF2+1/ER (J, K) /ER (J, K) 26210 RETURN 26220 ' 26230 *CPUDOFF 26240 NUD-NUD+1 26250 IF NUD-1 OR NUD-2 THEN A-0 ELSE A-1 26260 UDOFF-UDOFF*A+UD (J, K) /ER (J, K) /ER (J, K) 26270 EROFF=EROFF*A+1/ER (J, K) /ER (J, K) 26280 RETURN 26290 26300 '---- calculation of effects 26310 ' 26320 *CPEFFECT2 26330 EFFECT (J, K) = (UD (J, K) / UDOFF-1) *100 26340 EFFERR (J, K) -UD (J, K) /UDOFF*SQR ((ER (J, K) /UD (J, K)) ^2+ (EROFF/U DOFF) ^2) *100 26350 S-INT (ABS (EFFECT (J, K) / EFFERR (J, K))) 26360 IF S>2 THEN ERC (J, K) -2 ELSE ERC (J, K) -4+S 26370 RETURN 26380 ' 26390 '---- maximum effect 26400 26410 *CPEFFECTM

25690

25140 '

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26420 IF SP1-0 THEN P1-MAXEFFNO ELSE P1-SP1
26430 IF SP2 THEN UDOFF-UD (P2, K) :EROFF-ER (P2, K)
26440 EFFECT=UD (P1, K) /UDOFF-1
26450
EFFERR=UD (P1, K) /UDOFF* SQR ( (ER (P1, K) /UD (P1, K) ) ^2+ (EROFF/UDO
FF) ^2)
26460 S=INT (ABS (EFFECT/EFFERR))
26470 IF S>2 THEN EFFCL=2 ELSE EFFCL=4+S
26480
EFFECTM(K) =EFFECT*100:EFFERRM(K) =EFFERR*100:EFFCL(K) =EFFCL
26490 RETURN
26500 '
26510 '---- operation for no counting
26520 '
26530 *ERCP
26540 PS=" c h "+STR$ (CH+K*2) +":sec"+STR$ (L)
26550 MC=6:PS=PS+*のカウントが行われていません!*:GOSUB *DSPM
26560 RETURN
26570 '
26580 '##### error trap
26590
26600 '---- error
26610 '
26620 *DFNERR
26630
NERR(1) =56:NERR(2) =53:NERR(3) =68:NERR(4) =62:NERR(5) =0:NERR
26640 NERR(7) =61:NERR(8) =65:NERR(9) =55
26650 RETURN
26660 '
26670 *TRAP
26680 MC=2:GOSUB *DENERR
26690 '
26700 *TRAP1
26710 IF ERR<>NERR(1) THEN *TRAP2
26720 PS="ファイル記述に誤りがあります!"
26730 IF ERL-15220 THEN GOSUB *ERWAIT:RESUME *LDDATA
26740 IF ERL=15670 THEN GOSUB *ERWAIT:RESUME *LDDATA
26750 IF ERL-15880 THEN GOSUB *ERWAIT:RESUME *LDDATA
26760 PS=PS+"TMP. DATに保存しますので中断して下さい"
26770 IF ERL-14660 THEN GOSUB
*ERWAITP:FLNMS-DTDRIVES+"\TMP.DAT":RESUME
26780 IF ERL-14910 THEN COSUB
*ERWAITP:FLNMS-DTDRIVES+"\TMP.DAT":KILL FLNMS:RESUME
26790 IF ERL-15020 THEN GOSUB
*ERWAITP:FLNMS-DTDRIVES+"\TMP.DAT":KILL FLNMS:RESUME
26800 '
26810 *TRAP2
26820 IF ERR<>NERR(2) THEN *TRAP3
26830 PS="指定したファイルは存在しません!"
26840 IF ERL-15220 THEN GOSUB *ERWAIT:RESUME *LDOLD
26850 IF ERL-15670 THEN GOSUB *ERWAIT:RESUME *LDNEW1
26860 IF ERL=15880 THEN GOSUB *ERWAIT:RESUME *LDNEW1
26870 IF ERL-14410 THEN COLOR 7: RESUME *FILECHECK2
26880 '
26890 *TRAP3
26900 IF ERR<>NERR(3) THEN *TRAP4
26910 PS="ディスクに空き領域がありません。取り替えて下さい!"
26920 IF ERL=>14660 AND ERL=<14800 THEN GOSUB
*ERWAITP:CLOSE #1:RESUME *SVCONT
26930 IF ERL=>14810 THEN GOSUB *ERWAITP:CLOSE #1:RESUME
*SVRESULT
26940 GOTO *TRAP4
26950 *TRAP32
26960 PS="ディスクに空き領域がありません。取り替えて下さい!"
26970 IF EL=0 THEN GOSUB *ERWAITP:CLOSE #1:RETURN *SVCONT
26980 IF EL-1 THEN GOSUB *ERWAITP:CLOSE #1:RETURN
 SVRESULT
26990 '
27000 *TRAP4
27010 IF ERR<>NERR(4) THEN *TRAP5
27020 PS="ディスクが用意されていません!"
27030 IF ERL<>12060 THEN GOSUB *ERWAITP:RESUME
27040 PS="システムディスクが用意されていません!":GOSUB
*ERWAITP:RESUME
27050 '
27060 *TRAP5
27070 IF ERR<>NERR(5) THEN *TRAP6
27080 PS-*ブリンターが準備されていません!*
27090 IF ERL>=22680 AND ERL<=24110 THEN GOSUB
*ERWAITP:RESUME
```

```
27110 *TRAP6
27120 IF ERK<>NERR(6) THEN *TRAP7
27120 FS=*G P I Bが準備されていません! *
27140 IF ERL>=13470 AND ERL<=13580 THEN GOSUB
*ERWAITP:RESUME
27150 '
27160 *TRAP7
27170 IF ERR<>NERR(7) THEN *TRAP8
27180 PS="ディスクが保護されています。解除してください!"
 27190 GOSUB *ERWAITP:RESUME
27200 '
27210 *TRAP8
27220 IF ERR<>NERR(8) THEN *TRAP9
27230 IF ERL=14660 THEN KILL FLNMS:COLOR 7:RESUME
27240 IF ERL=14910 OR ERL=15020 THEN GOSUB *CL3:LOCATE
0,23:PRINT*同名のファイルが存在します。削除していいですか?
*;:GOSUB *ERINPT:RESUME
27250 '
 27260 *TRAP9
27270 IF ERR<>NERR(9) THEN *TRAPEXIT
27280 IF ERL=14510 THEN CLOSE #2:RESUME *RSVEXIT
27290 '
27300 '-----
27310 '
27320 *TRAPEXIT
27330 CONSOLE 0, 24, 1: PRINT "ERROR ("+STR$(ERR)+") IN
"+STR$ (ERL)
27340 BEEP:COLOR 7
27350 END
27360 '
27370 *ERWAITP
27380 GOSUB *DSPM:PRINT
27390 PRINT *用意が出来たら何かキーを押して下さい (ESC: プログラ
ムの中止) *;
27400 BEEP 1:KS-INPUTS(1):BEEP 0
27410 IF KS-"" THEN 27400 ELSE IF KS-CHRS(4H1B) THEN
 *TRAPEXIT
27420 GOSUB *CL3:MC-7:RETURN
27430 '
27440 *ERWAIT
27450 GOSUB *DSPM:BEEP:FOR K=1 TO 5000:NEXT K:MC=7
 27460 RETURN
27470 '
27480 *ERWAIT2
27490 MC-6:GOSUB *DSPM:BEEP:FOR K=1 TO 500:NEXT K:MC-7
27500 RETURN
27510 '
27520 *ERINPT
27530 PRINT * (Yes: 0, no: 1) *;
27540 BEEP 1:NK-1:GOSUB *IKEY
 27550 BEEP 0:ON ANSN GOTO *ERINPT2
27560 KILL FLNMS:MC=7:RETURN
27570 *ERINPT2:PS="ファイル名を指定して下さい":GOSUB *DSPM
27580 INPUT FLNEWNMS: FLNEWNMS-LEFTS (FLNEWNMS, 8)
27590 FLNMS=DTDRIVE$+"\result\"+FLNEWNMS+".dat":COLOR
7:RETURN
27600 '
27610 '---- STOP KEY エラー処理
27620 '
27630 *STTRAP
27640 PS="
27650 BEEP 1:AS=INPUTS(1):BEEP 0
27660 IF AS=CHRS(4HB) THEN STOP OFF ELSE STOP ON
27670 RETURN
27680 '
27690 '---- TEST ROUTINE
27700 '
27710 *TESTSTORE
27720 TWAIT% (0) =6H2
27730 FOR K=0 TO NCH
27740 FOR I=1 TO NRF*
27750
             FOR J=0 TO NSVDATA
               A#=10*I
U%(1,J,I,K)=INT(A#*(K+J+1)/32768!)
U%(0,J,I,K)=A#*(K+J+1)-U%(1,J,I,K)*32768#
27760
27770
27780
                 D*(1, J, I, K) =INT (A#*(K+J+5)/32768!)
D*(0, J, I, K) =A#*(K+J+5) -D*(1, J, I, K) *32768#
27790
27800
27810
              NEXT J
27820 NEXT I
27830 NEXT K
27840 RETURN
```

27100 '

| LAB1 | CNTR | ASM | | | rftimel | equ | 000ch | ; rf on time |
|----------|-----------|--------------------------|-----------|----------------|---------|---------|---------------|--------------------|
| | | | | | (coarse |) | | |
| | | | | | rftime2 | equ | 000eh | ; rf off time |
| , | | | | | (fine) | | | |
| , | Experime | intal control program, I | nitialize | routine | rfkillt | equ | 001Ch | ; rf effect kill |
| , | | | | | time | | | |
| ; | for con | croller NEC PC9801VX | by A.Kita | agawa | cttimel | equ | 0012h | ; count time 1 |
| ; | | | | | (coarse |) | | |
| ; | 1 | .991/01/25 | | | cttime2 | equ | 0014h | : count time 1 |
| ifl | | | | | (fine) | | | , count cano a |
| | tout | LABCNTR v.9.00 1.01 | | | cttime3 | equ | 0016h | t count time 2 |
| endif | | | | | lcoarse | 1 | | , count crime 2 |
| if2 | | | | | cttime4 | eau | 00185 | t count time 2 |
| | tout pa | th2 | | | (fine) | ada | | , count cime 2 |
| endif | | | | | cttime5 | eau | 001ab | t count time 1 |
| ; | | | | | lcoarse | equ | ooran | , count time 3 |
| ; | | | | | ctrimes | 0011 | 001 ch | · nount time 2 |
| ; | | | | | Ifinel | oda | 00101 | , count cime s |
| ; | Interfa | ce port address | | | (Line) | | | |
| ; | | | | | - | addrage | ing offerst i | las ef data |
| inport | equ | OladOh | ; I/O 1 | ort | | auuress | ing oriset i | or ri data |
| bmport | equ | 0lad4h | : | | hinds 1 | | 01 | |
| rfport | equ | 0lad2h | : | | Dicaci | equ | data far an | |
| ctport | equ | 0lad4h | | | hindeh | ; DIC | data for Re | selector |
| ptlctr | equ | 0lad6h | | | Dicach | equ | 10 | |
| rfbitpl | equ | 01ad8h | | | dadcii | equ | 20 | |
| rfbitph | equ | Oladah | | | | ; DA d | aca | |
| secport | equ | Oladch | | | dadtin | equ | Jn | |
| pt2ctr | equ | Oladeh | - | | dadt 21 | equ | 40 | |
| dachlh | equ | 01bd0b | · D/A | onverter | dadt 2h | equ | Sh | |
| dach11 | eau | 01bd2b | | on of the test | ;afpdt | equ | 4h | |
| dach2h | equi | 01bd4b | | | | ; ? | | |
| dach21 | equ | Olbdeb | | | ;gpdt | equ | 6h | |
| ct ch1 | equ | 01cd0h | | ar board 1 | dadt 31 | equ | | 6h |
| ctch2 | equ | Oledeb | ; count | er board I | | | ; DA data | for 7RF mode's VCO |
| at ch2 | equ | Olddob | | an based 2 | dadt 3h | equ | | 7h |
| atabd | equ | Olddon | ; count | er board 2 | dadt41 | equ | | 8h |
| CCCH4 | equ | oladon | ; | | dadt4h | equ | | 9h |
| CLCDS | equ | Oledon | ; count | er board 3 | dadt 51 | equ | | OAh |
| CECNO | equ | Uledan | ; | | dadt 5h | equ | | OBh |
| ; | | | | | dadt 61 | equ | | OCh |
| ; | address | ing offset for data | | | dadt 6h | equ | | ODh |
| ; | | | | | dadt71 | equ | | OEh |
| adnrf | equ | 900h | ; addre | ss of | dadt7h | equ | | OFh |
| number (| of rf | | | | trdt | equ | 10h | |
| adrfdt | equ | 904h | ; initi | al address | | ; Bit | data for TR- | 3133B |
| for rf o | data | | | | | | | |
| adctul | equ | 908h | ; initia | 1 address | | number | of roops | |
| for data | a U1 | | | | | | | |
| adctdl | equ | 90ch | ; | | lowait | equ | 063Ch | ;63Ch or 383h long |
| D1 | | | | | wait | | | |
| adctu2 | equ | 910h | ; initi | al address | loulse | equ | 02h | ; for control |
| for data | a U2 | | | | pulse | | | |
| adctd2 | equ | 914h | ; | | ; | | | |
| D2 | | | | | | control | signal | |
| adctsem | equ | 918h | ; initi | al address | | | | |
| for bean | a current | t data | | | bmstart | equ | 00010000b | |
| adwtlp | equ | 91ch | ; initia | l address | bmstop | equ | 0010000b | |
| for wait | ing time | e data | | | : | | | |
| adnlp | equ | 920h | ; initi | al address | screset | equ | 00000001b | |
| for numb | per of ro | pop | | | clock1 | equ | 000000105 | |
| adwork | equ | 924h | ; swap | address | ctgate | equ | 00000100b | |
| for data | | | | | clock2 | equ | 00001000b | |
| aderror | equ | 91ch | ; error | flag | ctarst | equ | 00000101b | |
| ; | | | | | ctac11 | equ | 00000110b | |
| ; | paramete | er transfer | | | ct gcl2 | equ | 00001100b | |
| ; | | | | | workend | equ | 10000000b | |
| nparal | equ | 12h | ; numbe | r of | · | oda | | |
| paramete | r * 2 | | | | "fetart | 0.000 | 00000015 | |
| npara2 | equ | 10h | ; numbe | r of | reston | equ | 000000105 | |
| paramete | r * 2-2 | | | | rfon | equ | 000001000 | |
| npara3 | equ | 24h | ; numbe | r of | rfoff | equ | 100000000 | |
| paramete | r * 4 | 100 | | | afabit | aqu | 100010000 | |
| ; | | | | | alpoit | equ | 010000000 | |
| ; a | ddressin | g offset for WAIT data | | | soreset | equ | 00000000 | |
| ; | | , | | | rigate | equ | 000000000 | |
| dummyt | equ | 0002h | : dummy | time | 110 | edn | OUCCOUD | |
| bmtime1 | equ | 0004b | : beam | on time | | | | |
| (coaree) | -44 | | , Dean | er er er | ; | counter | control bit | |
| hmtime? | equ | 00065 | · beam | on time | 1 | | 00111111 | |
| (fine) | -4- | | , beam | | holdall | equ | 001111116 | |
| aforime | equ | 00085 | . 150 6 | or | openall | equ | 111111116 | |
| excahage | DODUIA | ion | ALL I | | openl | equ | 101111111 | |
| omcool | Populat | 000ab | · have | noling | open2 | equ | 011111116 | |
| - ime | ada | ovodii | , Deam | sources and | ; | | | |
| e zine | | | | | | | | |

input bit push CX bp, adwork stopbit equ 000000106 mov di, adnrf mov beamon equ 00010000b 0010000b vom cx, npara2 beamoff equ 010000006 loop1: fton equ bx, ds: [bp] ftoff equ 00100000b errfrg equ 10001111b vom mov add ds:[di],bx di,0002h add bp, 0002h loop loopl code segment mov bp, adnrf assume cs:code, ds:code si,ds:dword ptr [bp] les cx,es:[si] including of macro part NOM ; sout 3 include lib\iocntr.asm main rootine program start begin: swap of resister push ds push es push ax bx push push CX push dx push di push si bp push masking of interrupt mov dx, 02h mov al,7fh dx, al out mov dx, Oah al, Oefh mov out dx, al mov dx, 1fh al, Ofh mov out dx, al 引数の受け渡し ; mov bp, bx di, adnlp TOM mov cx, nparal 10000: bx, ds: [bp] mov ds:[d1],bx d1,0002h NOM add add bp,0002h loop 10000 : mov bp, adnlp si, ds: dword ptr [bp] les cx, es:[si] mov scalar initializing ; counter ctch1, holdall counter ctch3, holdall counter ctch5, holdall ctreset ctchl ctreset ctch2 ctreset ctch3 ctreset ctch4 ctreset ctch5 ctreset ctch6 GP-IB initializing gpibini <---- NOT USE gpibifc gpibren large roop (1 sequence) ; gloop:

LAB2CNTR.ASM end program pop cx dec CX ercheck aderror jcxz retn jmp gloop ; flag set in erro or stop (from ercheck macro) erretn: mov bp, adnlp les si,ds:[bp] mov es:[si],cx : return to BASIC ; retn: gpibres <---- NOT USE ; ; bpcntr bmport, bmstop, off, lpulse ; reset of inetrupt masking mov dx, 02h mov al,01h dx, al out Nom dx, Oah mov al, Oe7h out dx, al dx, 1fh al, 00h vom NOM out dx, al return swaped resister ; pop bp si pop di pop pop dx cx pop bx DOD ax es pop pop ds retbas proc far iret retbas endp code ends 112 sout end endif

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```
IOCNTR. ASM
```

```
Macro routine libraries
       for LABCNTR SYSTEM by A. Kitagawa
              1991/01/25
               add rfaddec3 for 4rf or 2rf mode (T.
Ohtsubo 93.6.22)
if1
       tout IOCNTR v.9.01 1.01
endif
       tout 1
       LBL & VdG System
       bit control for I/O port
         port : port address
         data : 8bit data
bitchtr macro port, data
       push
               dx
              dx. port
       mov
              al, data
       mov
       out
              dx, al
       pop
              dx
       endm
      control pulse : send pulse from I/O port
         adrs : port address
        before : start bit
after : stop bit
         length : pulse length (nuber of constant
routine)
bpontr macro adrs, before, after, length
            dx '
       even
       push
              dx, adrs
       mov
              al, before
       MOV
       out
              dx, al
       wtloopc length
            al, after
       mov
       out
              dx, al
              dx
       pop
       endm
       beam waiting: waiting until set up bit input
         xx :set up bit (0: mask, 1: set up)
         inport : input port
bmwait macro xx
       local wait
       even
       push
              dx
              dx, inport
       mov
wait:
       in
              al,dx
       and
              al.xx
              ah, COh
       mov
       cmp
              ah, al
       jz
              wait
              dx
       pop
       endm
       error chedk
         adrs : address of error flag
         erretn : address for jumping in error
```

| | | adra | | local | loope |
|---------|-----------|---|---------|---------|--|
| ercneck | macro | adis | | even | |
| | local | cont | | nush | CX |
| | vom | pp, adrs | | nuch | 95 |
| | les | s1,ds:[bp] | | push | c3 |
| | mov | ax,0000 | | push | SI |
| | cmp | ax,es:[si] | | pusn | pp |
| | jz | cont | | vom | bp, adwilp |
| | tmp | erretn | | les | si,ds:[bp] |
| ont: | | | | add | si,wtimel |
| one. | andm | | | VOM | cx,es:[si] |
| | encan | | | jcxz | loope |
| | | | 10003: | | |
| | | | Toobe! | nuch | CX. |
| | | | | push | ex invair |
| | trapping | g of error | | mov | CK, Ipwalc |
| | | | 10004: | | |
| | port | : input port for error | | loop | 10004 |
| | frg | : masking of error flag | | pop | cx |
| | adrs | : address for error flag | | loop | 100p3 |
| | ah | : error without input signal; | loope: | | |
| rrin | macro | port.adrs.frg | | pop | dq |
| | mou | dy port | | pop | si |
| | 1 - | al dy | | DOD | es |
| | in | al, dx | | DOD | cx |
| | and | ax, Irg | | HELOOD | utime? |
| | mov | bp, adrs | | weldop | H L LING L |
| | les | s1, ds: [bp] | | encin | |
| | or | es:[s1],ax | ; | | |
| | endm | | ; | | |
| | | | ; | | |
| | | | ; | data ta | aking from counter board |
| | | | 1 | | |
| | const ant | 1000 | 1 | xx | : address of data stack |
| | conscane | 100b | | VV | : port address for counter board |
| | | | | | |
| | wtime | : number of loops | in data | macro | XX VV |
| ; | | | In_data | lagal | avit |
| tloopc | macro | wtime | | local | ext. |
| | local | loop3 | | local | exit2 |
| | even | | | local | lp |
| | push | cx | | push | dx |
| | mov | cx.wtime | | push | bp |
| 100021 | 1100 4 | CAT I CANO | | push | si |
| 10002: | 1 | 10003 | | push | ds |
| | 1000 | 100p3 | | nuch | 29 |
| | pop | CX | | pusii | 63 |
| | endm | | 11 | | du unit d |
| ; | | | | mov | dx, yy+4 |
| ; | | | | out | dx, al |
| ; | | | | MOM | dx, yy+1 |
| | short le | qoo | | in | al, dx |
| | | | | mov | ah, al |
| | adutl | · initial address of number of | f loop | mov | dx, yy |
| | utimo | off cat | | in | al, dx |
| | wcime | : OIL SEC | | mov | bp. xx |
| ; | | and the second se | | loc | el de dword otr (bol |
| wtloop | macro | wtime | | Ies | st, ds. david per (op) |
| | local | 100p3 | | add | ax, es:[s1] |
| | even | | | jns | exit |
| | nop | | | inc | es:word ptr [s1+2] |
| | push | CX | | sub | ax, 8000h |
| | nuch | 99 | | jmp | exit2 |
| | push | el | exit: | | |
| | push | ha | | push | cx |
| | push | op | | mov | cx. 02h |
| | vom | pp, adwc1p | 1 | | |
| | les | s1, ds: [bp] | ip: | 1000 | 10 |
| | add | si, wtime | | Toob | Th |
| | mov | cx,es:[si] | | pop | cx |
| 10003: | | | | nop | |
| | loop | 10003 | exit2: | | |
| | 000 | bo | | mov | es:[si],ax |
| | pop | ei | | pop | es |
| | pop | 51 | | DOD | ds |
| | pop | es | | 000 | ei |
| | pop | CX | | pop | bo |
| | endm | | | bob | op du |
| ; | | | | pop | ax |
| | | | | endm | |
| | | | ; | | |
| | long la | | ; | | |
| | Tond To | ob. | | | |
| | | | 1000 | rf dat | transfer |
| ; | adwtl | p :initial address of number of | Toob | LL Gall | |
| : | wtime | 1 :off set (large loop) | ; | | and the second |
| | wtime | 2 :off set (small loop) | 1 | | |
| | Inwat | : number of large loops | ; | | |
| | Thwar | | | (I/O co | ontroll sub routine): out put of set up |
| | | uning) uning? | addree | | |
| rcloopl | macro | wcimel, wcime2 | autres | | |
| | local | 100p3 | ; | | · mort address |
| | lacal | 10004 | ; | ad | · porc autress |
| | TOCAT | | | | |

| ; | n | : off set of output data |
|---------|-----------------|--|
| ; | si r | eg :RF data address |
| dtout | magro | ad a |
| acouc | nush | ad, n di |
| | mov | di.st |
| | add | di.n |
| | mov | al,es:[di] |
| | mov | dx, ad |
| | out | dx, al |
| | pop | di |
| | endm | |
| ; | | |
| ; | | |
| ; | | |
| ; | (GP-IB | Out mode) |
| ; | | |
| gpibou | t macro | |
| | push | es |
| | pusn | S1 |
| | push | CY CY |
| | add | si mdt |
| | mov | av estell |
| | inc | st |
| | inc | si |
| | mov | bx,es:[si] |
| | inc | si |
| | inc | si |
| | TOT | cx, es:[si] |
| | Nom | si, ax |
| | mov | es, bx |
| | mov | di,ax |
| | add | d1,03h |
| | mov | ax,0401h |
| | mov | bx, 03h |
| | int | Odlh |
| | pop | cx |
| | pop | di |
| | pop | si |
| | pop | es |
| | endm | |
| 1 | | |
| | | |
| : | (D/A OI | t mode) |
| ; | | |
| ; | | adrs : data address |
| ; | | chl, chh : DA port (#1 or #2) |
| ; | | dtl, dth : DA data (12bit) |
| ; | | |
| daout | macro | adrs, chl, chh, dtl, dth |
| | even | |
| | push | dx |
| | push | dq |
| | push | si |
| | push | ds |
| | push | es |
| | mov | bp, adrs |
| ; RF da | ta addre | ss -> si reg. |
| | dteut | si, as: aword ptr [bp] |
| | ucout | chin, den |
| | dtout | shi dti |
| | acout | |
| | pop | de |
| | pop | et |
| | pop | bo |
| | pop | dy |
| | endm | |
| : | | |
| | | |
| ; | | |
| ; | (Bit Ou | t mode |
| ; | | and the second sec |
| bitout | macro | |
| | dtout | rfbitph, bitdth |
| , | dtout | rfbitpl, bitdtl |
| · | | |
| · | bitchtr | ribitpi, oun |
| | bitcntr endm | ribitpi, oon |
| ; | bitchtr endm | ribitpi, oon |

| | af cont | mal has h | 1 | | |
|---------|----------|-----------|-----------|---------|------|
| | II CONC. | tor by c | out out | | |
| ; | | | | | |
| brdtout | t macro | adrs | | | |
| | bitcht | r rfbitp | 1,00h | | |
| | mov | bp. adr | 2 | | |
| · DE de | ta addr | | 1 | | |
| , | lea auur | | i reg. | | |
| | les | \$1, d\$: | awora pi | tr [bp] | |
| " | | | | | |
| 11 | gpibe | out | < | Not use | |
| 77 | push | ax | | | |
| | bitout | | | | |
| | drout | fai | rol afor | - | |
| | acour | L LIDI | cpi, alp | IC | |
| ;; | DICCI | ner ribi | cpi,ott | | |
| ;; | pop | ax | | | |
| | endm | | | | |
| ; | | | | | |
| | | | | | |
| | | | | | |
| : | TAKEDA | TD 71 770 | mada | | |
| | IAAEDA | 1431338 | mode | | |
| | | | | | |
| trdtout | macro | adrs | | | |
| | local | loop2 | | | |
| | push | CX | | | |
| :: | | | | | |
| | reset s | signal | | | |
| | | | | | |
| | - | du ser | Inch | | |
| | NOM. | ax, FID | icpn | | |
| | mov | a1,80h | | | |
| | out | dx, al | | | |
| | wtloopd | : 0010h | | | |
| | mov | al,00h | | | |
| | out | dx.al | | | |
| | wt loope | - 0004h | | | |
| | Actoope | | | | |
| " | data la | | | | |
| | data in | i signal | | | |
| ;; | | | | | |
| | mov | al, 20h | | | |
| | out | dx, al | | | |
| | TOT | bp, adr: | s | | |
| | les | si.ds: | dword of | r (bp) | |
| | add | si trdi | | | |
| | mou | ar oah | - | | |
| | 1104 | CA, 0011 | | | |
| | | | | | |
| ;; | data sig | nal | | | |
| 77 | | | | | |
| loop2: | | | | | |
| | mov | al,es: | [s1] | | |
| | add | al. 20h | | | |
| | out | dx.al | | | |
| | | | | | |
| | data ab | | 1 | | |
| | uaca sn | tire side | Id I | | |
| ;; | | | | | |
| | add | a1,10h | | | |
| | out | dx, al | | | |
| | wtloopc | 0008h | | | |
| | sub | al, 10h | | | |
| | out | dx, al | | | |
| | | | | | |
| | Increme | nt of da | ta sing | a1 | |
| | THETeme | ne or de | ica aring | | |
| ;; | | 1 | | | |
| | mov | a1, 200 | | | |
| | out | dx, al | | | |
| | wtloopc | 0004h | | | |
| | inc | si | | | |
| | inc | si | | | |
| | 1000 | 10002 | | | |
| | reeb | | | | |
| | stop dat | | ngal | | |
| | scop da | cd III SI | nyar | | |
| ;; | | | | | |
| | mov | al,00h | | | |
| | out | dx, al | | | |
| | wtloopc | 0008h | | | |
| | | | | | |
| | entry e | Ignal | | | |
| | | | | | |
| | mout | -1 405 | | | |
| | nov | a1,40n | | | |
| | out | dx, al | | | |
| | wtloopc | 0010h | | | |
| | mov | al,00h | | | |
| | out | dx, al | | | |
| :: | | | | | |
| | trappir | ng error | stop | | |
| | erappri | - or or | anab | | |
| " | | | | | |
```
errin inport, aderror, errfrg
;;
         pop
                   CX
          endm
.
1.....
          (main routine)
           rfdata : initial address of rf data
aderror : address of error flag
           errfrg : error flag
rfdtout macro rfdata
         even
         push
push
push
push
push
                  dx
                  bp
si
ds
                  es
::
         brdtout rfdata
         trdtout rfdata
***
          trapping error stop
         errin inport, aderror, errfrg
;;
         pop
                   es
         pop
                  ds
         pop
pop
pop
endm
                  si
                  bp
                  dx
1.....
         rf selector mode
rfslct macro
push dx
                 bp
si
ds
         push
        push sp
push si
push ds
push es
mov bp,adrfdt
les si,ds:dword ptr [bp]
dtout rfbitpl,bitdtl
bitcntr rfbitpl,00h
         pop
pop
pop
pop
endm
                   es
                  ds
                  si
                   þp
                   dx
          selection of counter open or hold
           ctch : counter address
hldsel :selection flag 3F: all ch hold
FF: all ch open
BF: 1ch open
7F: 2ch open
counter macro ctch, hldsel push dx
          mov
mov
out
                   dx, ctch+6
                  al, hldsel
dx, al
         pop
endm
                   dx
         counter reset
           ctch : counter address
ctreset macro ctch
         push
mov
                 dx
dx, ct ch
```

| | mov | al,00h | |
|---------|----------|--------------------------------|--|
| | out | dx, al | |
| | mov | dx, ctch+1 | |
| | mov | al,00h | |
| | out | dx, al | |
| | mov | dx.ctch+2 | |
| | out | dx.al | |
| | 000 | dx | |
| | andm | <u>un</u> | |
| | GIIGH | | |
| | | | |
| | | | |
| | | al coloction | |
| | ri conci | OI SELECTION | |
| | | hafara aftar F1 F2 | |
| contr | macro | belore, alter, ci, cz | |
| | even | | |
| | risict | the state staff leving | |
| | bpentr | riport, ristart, rioit, ipuise | |
| | bitchtr | riport, belore | |
| | in_data | adctul, ctchi | |
| | in_data | adctdl, ctch2 | |
| | in data | adetu2, etch3 | |
| | in_data | adctd2, ctcn4 | |
| | ctreset | ctchl | |
| | ctreset | ctch2 | |
| | ctreset | ctch3 | |
| | ctreset | ctch4 | |
| | wtloopl | t1, t2 | |
| | bitcntr | rfport, after | |
| | bpcntr | rfport, rfstop, after, lpulse | |
| | endm | | |
| | | | |
| | | | |
| | | | |
| | address | increment | |
| | | | |
| | n | : increment | |
| | | | |
| irsinc | macro | adress, n | |
| | push | bp | |
| | push | si | |
| | push | ds | |
| | mov | bp, adress | |
| | mov | s1, ds: [bp] | |
| | add | si.n | |
| | mov | [bp], si | |
| | DOD | ds | |
| | DOD | si | |
| | DOD | bp | |
| | endm | and the second second second | |
| | | | |
| | | | |
| | | | |
| | address | decrement | |
| | | | |
| | n | : decrement | |
| | | | |
| Irsdec | macro | adress, n | |
| | push | bp | |
| | push | si | |
| | push | ds | |
| | mov | bp. adress | |
| | TOV | si ds: [bp] | |
| | sub | ei.n | |
| | Sub | (bol si | |
| | mov | de | |
| | pop | al | |
| | pop | 31 | |
| | pop | pp | |
| | endm | | |
| | | | |
| | | | |
| | | an last inc | |
| (| councing | Selection | |
| | Laut an | 100 | |
| | (sub rou | ucine) | |
| Sec. 20 | | -1 -2 | |
| ountsb | macro | CI,C2 | |
| | opentr | coport, cograc, cogate, ipulse | |
| | bpentr | coport, cogerr, cogace, ipurse | |
| | wtloopl | | |
| | opentr | coport, cogerz, cogace, spurse | |
| | endm | | |
| | | | |
| | | | |
| | | | |

| ; | (main r | outine) |
|---|--|--|
| ; | | |
| | Secci | on : outpurt selection number |
| eignal. | | . number of separation of counting ga |
| | | tingromant of data address |
| | +1 | offset of parameter of time |
| | t2 | |
| | | |
| count | macro | section n ni t1 t2 |
| counc | local | 10 |
| | local | evit |
| | even | GALL |
| | push | CX |
| | bitcatr | secont, section |
| | counter | ctch1.openall |
| | counter | ctch3, openall |
| | bitchtr | ctport, ctgate |
| | adrsinc | adctul, ni |
| | adrsinc | adctd1, ni |
| | adrsinc | adctu2, ni |
| | adrsinc | adctd2, ni |
| | mov | cx, n |
| lp: | | |
| | countsb | t1,t2 |
| | dec | cx |
| | jcxz | exit |
| | jmp | lp |
| exit: | | Same and the second sec |
| | bitchtr | ctport, off |
| | counter | ctch1, holdall |
| | counter | ctch3, holdall |
| | bitchtr | secport, off |
| | pop | cx |
| | endm | |
| ; | | |
| ; | | |
| | | |
| ; | | |
| ; | beam coo | oling selection |
| ; | beam coo | bling selection |
| ; ; bmcool | beam coo macro | oling selection |
| ; ; bmcool | beam coo macro even | oling selection |
| ; ; bmcool | beam coo macro even wtloop b | oling selection |
| ; ; bmcool | beam coo macro even wtloop b endm | oling selection |
| ; ; bmcool | beam coo macro even wtloop b endm | oling selection |
| ; ; bmcool | beam coo macro even wtloop b endm | oling selection |
| ; ; bmcool ; ; | beam coo macro even wtloop b endm | controlbit for NER with condition |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm | controlbit for AFP with condition |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm wtput of | controlbit for AFP with condition |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm wtput of port | controlbit for AFP with condition : output port address |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm wtput of port before | controlbit for AFP with condition : output port address : output befor operation : output port address |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs | controlbit for AFP with condition : output port address : output befor operation : rf parameter address : condition for |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n | controlbit for AFP with condition : output port address : output befor operation : rf parameter address : condition flag |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t | controlbit for AFP with condition : output port address : output befor operation : f parameter address : condition flag : time parameter offset |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit | controlbit for AFP with condition : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop t endm utput of port before adrs n t afpbit | controlbit for AFP with condition : output port address : output befor operation : f parameter address : condition flag : time parameter offset : control bit |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit | controlbit for AFP with condition : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit | controlbit for AFP with condition : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t conf |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit | controlbit for AFP with condition : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop t endm utput of port before adrs n t afpbit macro local local even | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push | controlbit for AFP with condition : output port address : output befor operation : f parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push | controlbit for AFP with condition : output port address : output port address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop t endm utput of port before adrs n t afpbit | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local even push push push mov | controlbit for AFP with condition : output port address : output befor operation : f parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,0h |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push mov mov les | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port, before, adrs, n, t cont off bp es si dx al, Oh bp, adrs si, ds:dword ptr [bp] |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port, before, adrs, n, t cont off bp es si dx al, 0h bp, adrs si, ds:dword ptr [bp] si, afpdt |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,es:[si] |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,es:[si] bx,n |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,es:[si] bx,n off |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,n off al,afpbit |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,n off al,afpbit cont |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local local local local local sush push push push mov mov les add mov and jz mov | controlbit for AFP with condition : output port address : output port address : output befor operation : f parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,n off l,afpbit cont |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,es:[si] bx,n off al,afpbit cont al,Oh |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port, before, adrs, n, t cont off bp es si dx al, 0h bx,n off al, afpbit cont al, 0h |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port, before, adrs, n, t cont off bp es si dx al, 0h bx, es: [si] bx, n off al, afpbit cont al, 0h |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local local local local local local sush push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,0h bx,n off al,afpbit cont dx,port |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr [bp] si,afpdt bx,es:[si] bx,n off al,afpbit cont al,Oh dx,port al,before |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port, before, adrs, n, t cont off bp es si dx al, 0h bp, adrs si, ds:dword ptr [bp] si, afpdt bx, es:[si] bx,n off al, afpbit cont al, 0h dx, port al, before dx, al |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,0h bp,adrs si,ds:dword ptr [bp] si,afpdt bx,n off al,afpbit cont al,oh dx,port al,before dx,al t |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local local local local local local sush push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al, Oh bx,n off al,afpbit cont al,oh dx, port al,before d, al t al,before |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | beam coo macro even wtloop b endm utput of port before adrs n t afpbit macro local local even push push push push push push push push | controlbit for AFP with condition : output port address : output port address : output befor operation : rf parameter address : condition flag : time parameter offset : control bit port,before,adrs,n,t cont off bp es si dx al,Oh bp,adrs si,ds:dword ptr (bp) si,afpdt bx,es:[si] bx,n off al,afpbit cont al,Oh dx,port al,before dx,al t l,before dx,al |

```
pop
pop
pop
                    dx
                    si
                    es
bp
           endm
          rf kill selection
 rfkill macro
          even
wtloop rfkillt
          endm
          rf data address increment
rfadinc macro
          even
          adrsinc adrfdt,0020h
          endm
          rf data address dectrement
rfaddec3 macro
          even
          adrsdec adrfdt,0060h
          endm
          data address decrement
ctadinc macro n
          even
adrsinc adctul,n
adrsinc adctdl,n
          adrsinc adctu2, n
adrsinc adctd2, n
          endm
          read countin data
countin macro
          even
         even
in data adctul,ctchl
in data adctul,ctch2
in data adctu2,ctch3
in data adctu2,ctch4
          ctreset ctchl
ctreset ctch2
          ctreset ctch3
          ctreset ctch4
          endm
          read beam current data
                     : address for beam current data
: counter address for reading beam
            xx
            УУ
courrent data
in_sem macro
local
                   хх, уу
                   exit
          local
                   exit2
          local
                   lp
          even
          push
                   dx
                   bp
si
          push
          push
                   ds
          push
          push
                   es
         push
                   bx
::
         mov
                   bp, xx
                   si,ds:dword ptr [bp]
         les
```

| ;; | | | | | endm | |
|---|--|---|----|-------|--------|--|
| | counte | r yy, holdall | | ; | | |
| | mov | bx,0000h | | ; | | |
| | TOV | dx, vv+0Ch | | ; | | |
| | out | dx al | | | sout 2 | |
| | mou | dy unthe | | | | |
| | vom | dx, yy+on | | | | |
| | In | al, dx | | | | |
| | NOW | bl,al | | | | |
| | shl | bx, lh | | | | |
| | shl | bx, 1h | | | | |
| | add | si,bx | | | | |
| | | | | | | |
| | mov | dx. vv+4h | | | | |
| | out | dx al | | | | |
| | ouc | da, al | | | | |
| | mov | dx, yy+in | | | | |
| | 1n | al, dx | | | | |
| | mov | ah, al | | | | |
| | mov | dx, yy | | | | |
| | in | al,dx | | | | |
| ;; | | | | | | |
| | add | ax, es:[s1] | | | | |
| | ins | exit | | | | |
| | inc | es word ptr feit | 21 | | | |
| | eub | av BOOOD | -1 | | | |
| | den | ax, booon | | | | |
| andr | Jub | EXICZ | | | | |
| exit: | | | | | | |
| | push | CX | | | | |
| | mov | cx, 02h | | | | |
| lp: | | | | | | |
| | loop | lp | | | | |
| | pop | CX | | | | |
| | nop | | | | | |
| exit2: | | | | | | |
| | mov | ve [is] av | | | | |
| | ctreset | vv | | | | |
| | ctracat | 11 | | | | |
| | CLIESEL | уутоп | | | | |
| | counter | yy, openall | | | | |
| | pop | bx | | | | |
| | pop | es | | | | |
| | pop | ds | | | | |
| | pop | si | | | | |
| | pop | bp | | | | |
| | pop | dx | | | | |
| | endm | | | | | |
| ; | | | | | | |
| ; | | | | - | | |
| 7 | | | | | | |
| | GPIB CO | ntrol | | | | |
| | | | | | | |
| - | (initia | lize) | | | | |
| | (Anacad | 1100/ | | | | |
| mibini | - | | | | | |
| Abinini | macro | | | | | |
| | push | es | | | | |
| | mov | ax, cs | | | | |
| | add | ax, 098h | | | | |
| | mov | es, ax | | | | |
| | VOM | ah, 00h | | | | |
| | int | Odlh | | | | |
| | DOD | es | | | | |
| | endm | | | | | |
| | | | | | | |
| | | | | | | |
| | life set | -1 | | | | |
| | (ifc set | t) | | | | |
| ;;;; | (ifc set | t) | | | | |
| ; ; gpibifc | (ifc set | 2) | | | | |
| ; ; gpibifc | (ifc set macro push | bx | | | | |
| ; ; gpibifc | (ifc set macro push mov | bx bh, Olh | | | | |
| ; ; gpibifc | (ifc set macro push mov mov | bx bh, 01h ah, 01h | | | | |
| ; ; gpibifc | (ifc set macro push mov mov int | bx bh, Olh ah, Olh Odlh | | | | |
| ; ; gpibifc | (ifc set macro push mov mov int pop | bx bh, 01h ah, 01h Od1h bx | | | | |
| ; ; gpibifc | (ifc set macro push mov int pop endm | bx bh, 01h ah, 01h Od1h bx | | | | |
| ; ; gpibifc | (ifc set macro push mov mov int pop endm | bx bh, 0lh ah, 0lh 0dlh bx | | | | |
| ; ; gpibifc | (ifc set macro push mov mov int pop endm (remote | bx bh, 01h ah, 01h 0d1h bx enable) | | | | |
| ; ; gpibifc | (ifc set macro push mov int pop endm (remote | bx bh, 01h ah, 01h 0d1h bx enable) | | | | |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; | (ifc set macro push mov int pop endm (remote macro | bx bh,01h ah,01h Od1h bx enable) | | | | |
| ; ; gpibifc ; ; ; gpibren | (ifc set macro push mov int pop endm (remote macro mov | bx bh, 01h ah, 01h Od1h bx enable) ah, 02b | | | | |
| ; ; gpibifc ; ; ; gpibren | (ifc set macro push mov int pop endm (remote macro mov | bx bh, 01h ah, 01h 0d1h bx enable) ah, 02h 0d1b | | | | |
| ; ; gpibifc ; ; ; gpibren | (ifc set macro push mov mov int pop endm (remote macro mov int endm | bx bh, 01h ah, 01h od1h bx enable) ah, 02h od1h | | | | |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | (ifc set macro push mov mov int pop endm (remote macro mov int endm | bx bh, 01h ah, 01h 0d1h bx enable) ah, 02h 0d1h | | | | |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | (ifc set macro push mov int pop endm (remote macro mov int endm | bx bh, 01h ah, 01h Od1h bx enable) ah, 02h Od1h | | | | |
| ; ; gpibifc ; ; ; gpibren ; | (ifc set macro push mov mov int pop endm (remote macro mov int endm (reset) | bx bh, 01h ah, 01h od1h bx enable) ah, 02h od1h | | | | |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | (ifc set macro push mov mov int pop endm (remote mov int endm (reset) | bx bh,01h ah,01h od1h bx enable) ah,02h od1h | | | | |
| ; ; gpibifc ; ; ; gpibren ; ; ; ; gpibres | (ifc set macro push mov mov int pop endm (remote macro mov int endm (reset) macro | bx bh, 01h ah, 01h Od1h bx enable) ah, 02h Od1h | | | | |
| ; ; gpibifc ; ; gpibren ; ; ; gpibres | (ifc set macro push mov int pop endm (remote macro mov int endm (reset) macro mov | bx bh, 01h ah, 01h od1h bx enable) ah, 02h od1h | | | | |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | (ifc set macro push mov mov int pop endm (remote mov int endm (reset) macro mov int | bx bh, 01h ah, 01h od1h bx enable) ah, 02h od1h | | | | |
| ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; ; | (ifc set macro push mov mov int pop endm (remote mov int endm (reset) macro mov int | bx bh, 01h ah, 01h 0d1h bx enable) ah, 02h 0d1h ah, 03h 0d1h | | | | |

2APCNTR.ASM

;

end

| | NMR meas | surement program |
|--------|----------|--|
| - | | |
| ; | 2AP MODE | 2 |
| ; | | |
| ; | 2APCNTR | .M |
| ; | | |
| | title 21 | APCNTR Main routine |
| if1 | | |
| | Sout Nor | A 2APCNTR .ASM has been compiled |
| endif | | |
| ; | | and the second sec |
| ; | initial | izing program including |
| ; | | |
| | include | lab/lablcntr.asm |
| ; | | |
| main: | | |
| | in_sem | adct sem, ctch5 |
| | bpentr | bmport, bmstart, oir, ipuise |
| | ridtout | adridt |
| | WELOOPI | bmcimel, bmcimez |
| | ppcntr | bmport, bmscop, orr, ipuise |
| ; | hannal. | |
| | Dincool | |
| , | rfontr | rfon rfoff rftimel rftime? |
| | rfkill | rion, riorr, recimer, recimer |
| | TENTEL | |
| ' | count | 00000001b.01b.40b.cttimel.cttime2 |
| | count | |
| ' | rfadinc | |
| | boentr | ctport, workend, off, lpulse |
| ; | | |
| | dec | cx |
| | jcxz | extgl |
| | jmp | main |
| ; | | |
| extgl: | | |
| | countin | |
| | in_sem | adctsem, ctch5 |
| ; | | |
| ; | end prog | ram including |
| ; | | |
| | include | lab/lab2cntr.asm |

| 8APC | NTR.A | SM | | | | |
|--------|--|---|--|--|--|--|
| ! | NMR mean | ruemeth control | | | | |
| ; | SAP MODE | | | | | |
| ; | 8APCNTR | .м | | | | |
| | .sall title 87 | PCNTR Main routine | | | | |
| ifl | tout Nov | 8APCNTR .ASM has been compiled | | | | |
| endif | | | | | | |
| ; | initializ | zing part including | | | | |
| | include | lab\lablcntr.asm | | | | |
| | ctadinc | Och | | | | |
| main: | 2 | | | | | |
| | in_sem bpcntr rfdtout | adcisem, ctch5 bmport, bmstart, off, lpulse adrfdt bmrime1 bmrime2 | | | | |
| | bpentr | bmport, bmstop, off, lpulse | | | | |
| , | bmcool | | | | | |
| ; | rfentr rfkill | off, rfoff, rftime1, rftime2 | | | | |
| ; | count | 00000001b, 01h, 34h, cttime3, cttime4 | | | | |
| ; | rfentr rfkill | rfon, rfoff, rftime1, rftime2 | | | | |
| ; | count | 00000010b,01h,04h,cttimel,cttime2 | | | | |
| ; | rfcntr rfkill | rfon, rfoff, rftime1, rftime2 | | | | |
| ; | in_sem bpcntr rfdtout wtloopl bpcntr | adctsem, ctch5 bmport, bmstart, off, lpulse adrfdt bmtimel, bmtime2 bmport, bmstop, off, lpulse | | | | |
| ; | bmcool | | | | | |
| ; | rfentr rfkill | rfon, rfoff, rftimel, rftime2 | | | | |
| ; | count | 00000100b,01h,04h,cttime3,cttime4 | | | | |
| ; | rfontr rfkill | rfon, rfoff, rftime1, rftime2 | | | | |
| ; | count | 00001000b, 01h, 04h, cttimel, cttime2 | | | | |
| ; | rfcntr rfkill | off, rfoff, rftimel, rftime2 | | | | |
| ; | rfadinc bpcntr | ctport, workend, off, lpulse | | | | |
| ; | dec jcxz jmp | cx extgl main | | | | |
| extgl: | 10.000 | adot sem. ct cb5 | | | | |
| ; | In sent | ram including | | | | |
| ; | and prog | Lablab2cotr asm | | | | |
| ; | Include | Idu/Idu/Chur, a and | | | | |

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2RFCNTR.ASM

count 00000001b,01h,40h,cttime1,cttime2

NMR measurement program : 2RF 2AP MODE (RF ON / OFF) RF 1,2 * 5 ; (3,4 are dummy) used by Frequency synsesizer 2RF-2AP using frequency synsesizer ; extgl: RF data for '4RF 2AP MODE' can be used. Please set dummy data for No. 3 and 4 : RF. ; 2RFCNTR.M : by Moichi ; modified by A.K. 1991/11/08 ; This is the my Last control program ; for LABCNTR system. ; modified by T.O. 1993.5.17 for control TR-3133 at 10MHz switching ; title 2RFCNTR Main routine ifl Now 2RFCNTR.ASM has been compiled endif initializing program including ; ; include lab/lablcntr.asm ; ctadinc 04h main: in_sem adctsem,ctch5 rfdtout adrfdt ; for 10MHz switching bpcntr bmport, bmstart, off, lpulse wtloopl bmtimel, bmtime2 bpcntr bmport, bmstop, off, lpulse ; bmcool ; bpcntr rfport, rfon, rfon, lpulse push cx mov ; for 5 rf loop rflpl: push cx cx,005h rfdtout adrfdt bpcntr rfport, 045h, 004h, 1pulse ; select RG1 0100 0101 wtloopl rftimel,rftime2 rfadinc rfdtout adrfdt bpcntr rfport,025h,004h,1pulse ; select RG2 0010 0101 wtloopl rftimel, rftime2 rfadinc rfadinc pop dec CX CX jcxz rfaddec3 contl rflpl jmp pop cx bpcntr rfport, rfoff, rfoff, lpulse rfkill cont1: count 00000001b, 01h, 3ch, cttimel, cttime2 :

countin rfadinc dec cx icxz extal jmp main countin in_sem adctsem, ctch5 end program including include lab/lab2cntr.asm end



