Brown and MacDonald point out that the estimates made by us of the lowest temperatures measurable with the thermal noise generated by a large resistance at the control grid of an electrometer tube neglect the flicker effect. For this reason, they believe that such a device would only be practical after a "drastic modification." The effect mentioned was omitted from our previous discussion because it appears likely that with an electrometer tube such as the Western Electric D-96475 operating at the necessarily low frequency of 5 cycles/second, the flicker noise can be substantially cancelled out by utilizing the screen grid, as in the familiar balanced circuit of Dubridge and Brown.[2]

The belief entertained by Brown and MacDonald that we have "apparently overlooked" a fundamental principle, namely the universal applicability of Nyquist's theorem, we can only attribute to the occurrence of an erroneous statement in our previous note, namely that an input resistance of 10^5 ohms is adequate for the successful operation of a piezoelectric thermometer. The statement in question should read that an input resistance of 10^{13} ohms should be adequate for such operation. Except for this error, we believe that there is no basis for drawing the conclusion of Brown and MacDonald that we claim any fundamental difference in the behavior of a piezoelectric thermometer from that of a resistance thermometer; the advantage is that of practicability. Although it is certainly more expeditious to make numerical estimates by applying Nyquist's theorem to experimentally determined dynamic resistances, it appeared worth while to derive our formula (4) expressing the noise voltage directly in terms of crystal constants, since this expression not only permits estimates of optimum crystal dimensions, but also reveals the inherent frequency limitation in such devices in a manner not immediately apparent from a consideration of Nyquist's formula itself.

The fact that the advantages of a piezoelectric thermometer are merely of a practical nature is not unimportant. Thus the piezoelectric thermometer avoids the following intrinsic difficulties associated with the first device described: (1) the long measurement time associated with low frequencies, owing to limitations imposed on band width by input capacities, (2) the necessity of minimizing microphonics, low frequency power supply variations, and flicker effects, and (3) the temperature-independence of the resistance, since the equivalent dynamic resistance of the piezoelectric crystal may be controlled by temperature-independent mechanical loading.

The principal disadvantage associated with a piezoelectric thermometer is the increased difficulty of obtaining a sufficiently high input resistance at the higher frequencies involved. However, recent developments in miniature tubes with small electron transit times (e.g., the RCA 6AK5) appear to offer some promise of meeting the required specifications.

In conclusion, it appears worth while to mention that Professor W. W. Hansen[3] has kindly pointed out to us that it may be advantageous to consider the use of a modification of the ingenious method recently described by Dicke[4] for the determination of temperature by the measurement of microwave radiation. A preliminary study by us of the design factors involved indicates that it should be possible to measure temperatures of the order of 0.1°K to 0.01°K using ordinary vacuum tubes with a noise generating resistance as low as 10^5 ohms.

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[4] R. H. Dicke, Rev. Sci. Inst. **17**, 268 (1946).

The Angular Distribution of Gamma-Rays in Na^{24}, Co^{60}, Y^{88}*

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WHEN two gamma-rays are emitted successively in the process of nuclear de-excitation, a distribution in angle is expected for the second gamma-ray relative to the first.[1,2] Coincidence studies to observe this angular correlation have been largely unsuccessful in showing any distribution apart from isotropy.[3,4]

The radioactive nuclei Na^{24}, Co^{60}, Y^{88} are particularly suited for deciding whether or not the above effect can be observed for the following reasons: (i) each of the radioactive transformations is followed by two successive gamma-ray transitions; (ii) the gamma-ray transitions occur, respectively, in the nuclei Mg^{24}, Ni^{60}, Sr^{88}. These nuclei are of the even-even type, and hence possess in their ground state no angular momentum. Zero to zero transitions are forbidden for gamma-ray transitions, hence the intermediate state cannot have an angular momentum zero. But theory shows that in the cases of these nuclei, only an intermediate state with an angular momentum of zero can give rise to an isotropic distribution. It follows, therefore, that in the cases of these nuclei, a distribution apart from isotropy is known to exist. It can further be said that as far as theory goes, the minimum asymmetry to be expected from all permissible angular momentum and parity assignments is seven percent; (iii) the respective half-lives of 14.8 hr., 5 yr., and 105 days are sufficiently long so that complications do not arise due to short half-lives.

The expected distribution is a power series in $\cos^2\theta$. The instrument used in the investigation subtended a solid angle of 0.3 steradian at the source. Analysis showed that an observed distribution would differ, because of finite solid angles, from the real distribution by only a couple of percent. Because of the low coincidence rates, and because the distribution has its extremes at the angles 90° and 180°, counting was restricted to these angles. The results are tabulated in Table I.

TABLE I. Observations of γ-ray emission at 90° and 180°.

Nucleus	180°	90°	Difference	Net rate at 90°	Percent asymmetry
Y^{88}	1.12±0.02 c.p.m.	1.08±0.02 c.p.m.	0.04±0.03 c.p.m.	0.78 c.p.m.	5.1±3.9
Co^{60}	1.67±0.04	1.63±0.04	0.04±0.06	0.56	7.1±10.
Na^{24}	3671±60*	3613±60*	58±84*	1800*	3.2±4.7

* Total coincidence

TABLE II. Estimated line widths for electric quadripole radiation.

Nucleus	γ-ray	τ	ΔE line width	ΔE hyperfine
Mg^{24}	2.75 Mev	1.4×10^{-12} sec.	2.8×10^{-3} ev	0.01×10^{-3} ev
	1.38	22.	0.18	
Ni^{60}	1.30	19.	0.21	0.08
	1.10	38.	0.11	
Sr^{88}	1.90	35.	0.11	0.12
	0.91	680.	0.006	

It is improbable from these data that an asymmetry can exist, though one as large as the minimum expected is not completely excluded. Until it can be demonstrated otherwise, magnetic coupling between the nucleus and the atomic electrons seems the most plausible reason for the distribution not being observed. Such a coupling will interfere with the distribution unless the lifetime of the nuclear state is very small compared with the precession times of the nuclear moment in the magnetic field of the electrons; that is, the width of the gamma-state must be large compared with the hyperfine splitting. Table II gives a summary of the estimated line widths for electric quadripole radiation, based upon a calculation of Lowen.[5] The right-hand column which is this coupling with a penetrating electron is not too significant because the materials were all in the solid state. However, consideration must be taken of the fact that when the gamma-rays are emitted, the atoms are most probably in deeper than optical degree of excitation due to the initial radioactive transformations. The right-hand column represents then a reasonable lower limit of coupling energy, and it is seen that the conditions for observing the distribution may not be met, in the case of quadra—or higher pole radiation.

A limited attempt was made to de-couple nucleus and electrons by the use of strong magnetic fields. The argument is that according to the assumptions of the theory, the components of angular momentum in the direction of the first gamma-rays are constants of motion. In the limit of an infinitely strong magnetic field parallel to the first gamma-ray, the nucleus and the atom become de-coupled, with their components along the magnetic field constant, thus satisfying the condition assumed by theory. Since this is true for strong fields, it should be true to lesser degree for finite fields. The experiment was attempted with a magnetic field of about 17,000 gauss. Counters were placed in the pole pieces of the magnet, 180° apart, and a difference was sought in the coincidence rate with the field on and the field off. No effect was observed outside the error of the data which was only sufficient to detect asymmetries of forty percent or greater in the form of the distribution. It is regretted that this work was terminated by the war and in the light of the paper of G. Goertzel in this issue of *The Physical Review* it is desirable to pursue the investigation further.

* Part of a thesis submitted to the faculty of Massachusetts Institute of Technology in partial fulfillment of the requirements of the Degree of Doctor of Philosophy, February, 1944.

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Stark and Zeeman Effects in the Inversion Spectrum of Ammonia

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WE have observed Stark and Zeeman effects in the microwave absorption spectrum of NH_3 in the 1.25-cm region, using ammonia containing both N^{14} and N^{15}.

Ordinarily a rotational level of a symmetric top molecule is split by an electric field into $2J+1$ components, corresponding to the different values of M where $-J\leqslant M\leqslant J$. Because of the high frequency of inversion of the NH_3 molecule, however, there is no first-order Stark effect. The second-order effect is proportional to the square of the electric field E, and to M^2. Thus there are only $J+1$ levels corresponding to the different values of M^2.

Our d.c. electric field was parallel to the high frequency field as described previously,[1] so that only transitions corresponding to $\Delta M=0$ could be observed, with the transition $M=0$ to $M=0$ forbidden.

The increase in frequency produced by the electric field E is described approximately by the equation

$$\Delta\nu(\text{cm}^{-1})=1.5\times10^{-4}\cdot[MK/J(J+1)]^2\cdot E^2,$$

where E is given in e.s.u. This equation applies to ammonia made with either N^{14} or N^{15}.

A shift of this amount corresponds roughly to a semi-permanent dipole moment of 1.5×10^{-18} e.s.u.

A magnetic field of 6600 oersteds perpendicular to the high frequency field splits a rotational line into a doublet with a separation of approximately 2.0×10^{-4} cm^{-1}, independent of J and K within experimental error. A magnetic field parallel to the high frequency electric field produced no observable effect.

Good,[2] working with ordinary ammonia, has reported that several of the rotational lines exhibit a hyperfine structure. We have now resolved a hyperfine structure in most of the rotational lines of $N^{14}H_3$. We interpret the structure as a splitting of the rotational energy levels by a coupling between the angular momentum of the molecule as a whole and the spin of the nitrogen nucleus. This interaction appears to result from an electric quadrupole moment of the N^{14} nucleus, and is described by the equation

$$\Delta\nu=[e^2qQ]\cdot\left(\frac{3K^2}{2J(J+1)}-\frac{1}{2}\right)\cdot\left[\frac{(\tfrac{3}{2})C(C+1)-2J(J+1)I(I+1)}{(2J-1)(2J+3)(2I-1)(2I+3)}\right],$$

where

$$C=F(F+1)-I(I+1)-J(J+1),$$
$$I=1,$$
$$F=J+0,\ \pm1,$$
$$[e^2qQ]=3.4\times10^{-4}\text{ cm}^{-1}.$$

$N^{15}H_3$ shows no trace of hyperfine structure. This is to be expected since N^{15} has a spin of $\frac{1}{2}$. The frequencies of the rotational lines of $N^{15}H_3$ are given approximately by the equation

$$\nu(\text{cm}^{-1})=0.7575-0.0047(J^2+J-K^2)+0.0019K^2.$$

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