Crawford, and Locke are apparently due to pressure, while there are many reasons to believe that the absorption lines observed by Herzberg are due to the change of the quadrupole moment.[4]

The present author proposed a theory of the pressure absorption[3] by which the intensity of this absorption is given by

$$I_P=\frac{192\pi^4\nu P^2}{25hcR_0^5}n^2(a|\alpha|b)^2, \quad (1)$$

where ν is the frequency of the absorption line (which corresponds to the transition $a\rightarrow b$), P is the quadrupole moment of the molecule, n is the number of molecules in unit volume, $(a|\alpha|b)$ is the ab-matrix element of the polarizability α, and R_0 is the shortest distance to which the molecules can approach to each other.

For the Q-branch of 0–1 lines, the experimental results of Welsh and others[2] gives $I=3.41\times10^7$ cm^{-1} at 1 atmos. In this case $\nu=1.246\times10^{14}$ sec.$^{-1}$, $n=2.98\times10^{19}$ cm^{-3}, and $P=5.85\times10^{-27}$ c.g.s. e.s.u.[5] From the transport phenomena of hydrogen gas we obtain $R_0=2.72$A. Thus $(0|\alpha|1)$ must be 1.83×10^{-25} in order to explain the experimental results by Eq. (1). Although the theoretical estimation[6] by the Heitler-London wave function yields $(0|\alpha|1)=0.53\times10^{-25}$, it is not an absurd value when compared to the value of polarizability (an average of the diagonal elements of α) 8.02×10^{-25}.

The intensity of the pressure absorption in the harmonic lines 0–2, 0–3 due to the anharmonisity were estimated as follows.

The frequencies of the lines observed by Herzberg[1] fit well with the theoretical one, if we put $D=8.2496\times10^{-12}$ erg, $a=1.8553\times10^8$ cm^{-1} and $r_e=7.501\times10^{-8}$ cm in the Morse potential

$$U=D(1-\exp[-a(r-r_e)])^2.$$

If we put $\alpha(r)=\alpha_e+\alpha_e'(r-r_e)+\cdots$ and neglecting the terms higher than α_e'', it can be shown that the matrix elements of α calculated by the Morse wave function[7] are

$$(0|\alpha|1)=\alpha_e'\frac{(k-3)^{\frac{1}{2}}}{a}\{\psi(k-1)-\psi(k-2)\},$$

$$(0|\alpha|2)=\alpha_e'\frac{1}{\sqrt{2}a}\left(\frac{k-5}{k-2}\right)^{\frac{1}{2}}\{-(k-2)\psi(k-1)+2(k-3)\psi(k-2)-(k-4)\psi(k-3)\}, \quad (2)$$

$$(0|\alpha|3)=\alpha_e'\frac{1}{\sqrt{6}a}\left\{\frac{k-7}{(k-2)(k-3)}\right\}^{\frac{1}{2}}\{-(k-2)(k-3)\psi(k-1)+3(k-3)(k-4)\psi(k-2)-3(k-4)(k-5)\psi(k-3)+(k-5)(k-6)\psi(k-4)\},$$

where $\psi(x)$ is the digamma function, and

$$k=4\pi[(2\mu D)^{\frac{1}{2}}/ah].$$

By the above obtained numerical values we obtain

$$(0|\alpha|1)=9.281\cdot10^{-10}\alpha_e',$$
$$(0|\alpha|2)=-1.039\cdot10^{-10}\alpha_e',$$
$$(0|\alpha|3)=-2.034\cdot10^{-11}\alpha_e'.$$

Thus the intensity ratio of the absorption lines calculated by Eq. (1) is

$$I_{01}:I_{02}:I_{03}=1:0.0225:0.00094. \quad (3)$$

The intensities of the pressure absorption for the Q-branch of each band calculated by it, is shown in Table I, together with the values of intensity of the quadrupole absorption calculated by the James-Coolidge value.[5]

TABLE I. Intensity of each absorption. (Q-branch, at 1 atmos., 300°K, in cm^{-1}).

Absorption lines	0–1	0–2	0–3
$I_Q\times10^{-3}$	1.8	1.65	0.34
$I_P\times10^{-7}$	3.4	0.086	0.0022
$(I_Q/I_P)\times10^5$	5	190	1500

The ratio I_Q/I_P is always less than 10^{-1}, the pressure absorption being larger. We must, however, take note of the fact that what is measured is not the integrated intensity I itself, but rather the absorption coefficient. The maximum absorption coefficient of each line is proportional to I, and inversely proportional to the width of the line. The width of the pressure absorption is about 10^2 cm^{-1}, while that of the quadrupole absorption may be assumed to be about 10^{-3} cm^{-1}. Thus the ratio of the maximum absorption coefficient of two absorptions for each line may be given by the figures in the last row of Table I, from which we can see that even at 10 atmos. the quadrupole absorption may be observed in the harmonic lines, while in the 0–1 lines the pressure absorption is predominant as we see in the experiments.

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[1] G. Herzberg, Nature **163**, 170 (1949).
[2] Welsh, Crawford, and Locke, Phys. Rev. **76**, 580 (1949).
[3] M. Mizushima, Phys. Rev. **76**, 1268 (1949).
[4] G. Herzberg (private communication).
[5] H. M. James and A. S. Coolidge, Astrophys. J. **87**, 447 (1938).
[6] B. Mrowka, Zeits. f. Physik **84**, 448 (1933).
[7] P. M. Morse, Phys. Rev. **34**, 57 (1929).

Search for Photons Emitted by Long-Life Species of Nickel

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AVAILABLE information concerning disintegrations of two species of nickel, Ni^{59} and Ni^{63}, is confined to their half-lives. The $T_{\frac{1}{2}}$ for Ni^{59} disintegrating by orbital electron capture was estimated to be about $(2\text{–}3)\times10^5$ yr. and that for Ni^{63}, disintegrating by negatron emission, several hundred years.[1,2] The beta-disintegration u.e. of Ni^{63} was given as $\sim$50 kev.

The present study of long-life isotopes of nickel was made with 9.7 g of nickel activated at Oak Ridge National Laboratory of AEC. The nickel salt was chemically purified by repeated precipitation of nickel in the presence of carriers for radioactive impurities.

Due to the low specific activity of the nickel species and to their very long lives, the study was made with a G-M counter and with a cloud chamber, both mainly for the emission of photons. A specially constructed large aluminum window gamma-tube was employed. To secure low background and small fluctuations of the tube, a sample of active nickel was shielded and the emitted radiation was collimated.

The results obtained showed the presence of photons of the following energies: 7.5±1 kev, 15±2 kev, and 38±3 kev, by absorption in aluminum. Absorption of radiation in copper verified the presence of photon of 38±3 kev and indicated the existence of photon of 80±5 kev energy. The order of relative intensities of photons of 7.5±1 kev, 15±2 kev, 38±3 kev, and 80±5 kev was estimated as 6:1:1:1, respectively.

The very low intensity of radiation did not allow the establishment of the presence of higher energy photons. Absorption in lead showed the existence of at least one photon of energy higher than 500 kev.

If it is assumed that the 7.5±1-kev photon is due to x-rays of orbital electron capture and to internal conversions, the emitted gamma-rays can be ascribed to Ni^{59}.

Electron tracks in the cloud chamber with and without a magnetic field revealed the presence of monochromatic electron groups.

An attempt to obtain a continuous spectrum of beta-disintegration of Ni^{63} in the cloud chamber was not successful.

Since Ni^{59} disintegrates into Co^{59} and Ni^{63} into Cu^{63} efforts were made to obtain information on the already known excited

states of Co^{59} and Cu^{63}. No experimental evidence was secured for the existence of such states in the disintegration of Ni^{59} and Ni^{63}.

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[1] G. Friedlander, Progress Report, Brookhaven National Laboratories (January 1–June 30, 1949).
[2] Q. T. Seaborg and I. Perlman, Rev. Mod. Phys. 20, 596 (1948).

Non-Linear I-V Characteristic of Ge at Very Low Temperatures

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BOTH Estermann[1] and Gerritsen[2] have found in pure Ge samples, in the temperature region of liquid He, that the current-voltage relation is non-linear and usually shows a small asymmetry. At sufficiently high temperatures, however, the non-linearity and asymmetry disappear and at room temperature, a linear $I-V$ characteristic is found.

These facts may be qualitatively understood if we assume, as was done by Estermann, that in the "pure" samples, the concentrations of donors and acceptors are (almost) equal. In that case, we must expect local fluctuations in the concentrations causing the existence of n type domains and p type domains with $n-p$ barriers between them. As has been pointed out by James,[3] who considered an analogous situation for PbS, we may expect that the domains will combine to form a small number of continuous n type paths or p type paths. In each path there will be islands and pensinsulas of the other type. The current will mainly flow in the n paths and p paths, avoiding the islands and peninsulas and therefore it uses only a fraction of the total cross section. This is so because the $n-p$ barriers are quite high at low temperatures namely about 0.7 ev for Ge.

A qualitative explanation of the observed non-linear $I-V$ characteristic follows now directly from the above picture. For let us consider a p type island in an n type path with the electron current flowing in the direction of the arrow (see Fig. 1). The flow

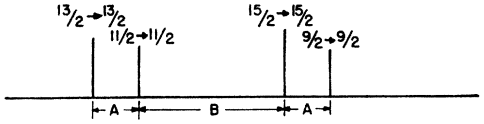

FIG. 1.

through the island will be prevented by barrier a as the flow is in the backward direction for this barrier. As soon, however, as the voltage over the specimen has been increased to such a value that the voltage difference between a and b becomes 0.7 V, the barrier at a will be wiped out and the current will flow through the island too. An analogous reasoning holds for the peninsulas. Also if a favorable voltage difference develops between a certain point of an n path and the adjacent point of a p path, the barrier between them may break down, thus causing a more favorable flow pattern. The described effects will cause a non-linear $I-V$ characteristic of the observed type in which the current increases "too much" with increasing voltage. At higher temperatures the effect will be much less marked because the conductivity increases so quickly that it will be hard to build up sufficient voltage between a and b without causing disturbing heat effects at the same time.

The slope of the characteristic at $V=0$ gives the resistance of the continuous n paths and p paths and its temperature dependence should be characteristic of the material without barriers.

In order to account for the asymmetry we must realize that the electron current can pass from the p path to the adjacent n path but not in the other direction. Therefore, the flow pattern will usually not be the same for both directions of applied voltage. As, however, there are a large number of obstructions for the current in both directions we must expect only a small resultant asymmetry. As this asymmetry is caused by the recifying property of $n-p$ barriers, it will not show up for voltage drops across the barrier corresponding with kT. Therefore we will find less asymmetry at higher temperatures where the applied voltage will be low in order to limit the current density. Furthermore, the barrier height is less at higher temperatures.

The shape of the $I-V$ characteristic is determined by the distribution of the $n-p$ barriers and the conductivities of the n and p paths. The fact that the shape of the $I-V$ characteristic is almost invariant with temperature in the liquid He range is in accordance with the experimental result that the conductivity of the n and p paths is independent of temperature in that range. However, an explanation for this behavior of the conductivity appears to be missing.

If the above considerations are correct we expect the high frequency resistance of pure Ge in the liquid He range to be considerably lower than the d.c. resistance and the $I-V$ characteristic shluld be linear at very high frequencies.

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[1] I. Estermann, International Conference on the Physics of Very Low Temperatures, Cambridge, Massachusetts, 1949.
[2] A. N. Gerritsen, Physica 15, 427 (1949).
[3] H. M. James, Science 110, 254 (1949).

A Preliminary Report on the Fine Structure of the Microwave Absorption Spectrum of Oxygen*

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USING a Zeeman modulation spectrograph, we have observed the microwave absorption spectrum of oxygen at low pressures ($\sim 10^{-1}$ millimeters of Hg), where the fine structure is completely resolved. Though several previous studies of the microwave absorption of oxygen have been made at pressures of the order of an atmosphere, no one has before detected this absorption at sufficiently low pressures to resolve completely the fine structure,** which has been theoretically predicted by Van Vleck.[1] Some experimental evidence for the fine structure was obtained by Beringer[2] in his wartime measurement of the resonance absorption of oxygen in the region of 5 millimeters wave-length. Recently, this work has been repeated by Strandberg, Meng, and Ingersoll[3] at pressures of 80 cm of Hg with the result that somewhat better evidence was obtained for the fine structure. The overlapping absorption of many lines at such high pressure prevented the accurate measurement of several properties of oxygen such as the line breadth parameter and the spacing of the fine structure levels.

In our work an absorption line is detected by a narrow-band, phase sensitive detector and is displayed on an Esterline Angus Automatic Recorder. The receiver operates at 4000 c.p.s. The absorption lines are modulated at the same frequency with an alternating magnetic field, which is applied by means of a solenoid which is placed around the wave guide cell. The field strength used in modulation is usually the order of a gauss. To reduce eddy currents, the wave guide cell is slotted down the center.

So far, sixteen of the fine structure lines have been detected and measured with a cavity wave meter. These tentative frequencies are listed in Table I. They are now being measured more precisely