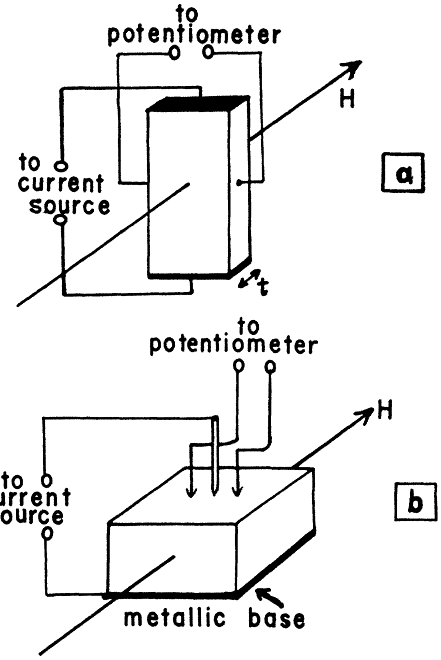

FIG. 1. (a) Conventional arrangement for measuring transverse Hall effect in a bulk semiconductor. (b) Method for determining Hall effect in the neighborhood of a metal-semiconductor point contact.

*vs.* temperature enable one to separate the electron and hole components.[1]

Information of this type is much needed for an understanding of conduction mechanisms in point contact rectifiers and transistors. It would seem possible, using the configuration illustrated in Fig. 1(b), to perform a Hall effect measurement in a point contact. Two metal probes are placed diametrically opposite from the current-carrying central contact and a magnetic field is applied in a direction perpendicular to the plane made by them. Assuming (1) the semiconductor resistivity is homogeneous, isotropic, and independent of current density and magnetic field, (2) the distance of the probes from the center contact is large compared with the radius of the contact, one can show that an e.m.f. is induced between the probes given by $E=RHI(1/d)$, where $d$ is the distance between the probes. Thus, one may expect to observe a Hall e.m.f. comparable in magnitude to that observed in a plate as in Fig. 1(a). In germanium crystals, most of the assumptions above are generally not correct, especially if one is dealing with contacts showing rectification, photoelectric effects or surface conduction, and a really quantitative study of such Hall effects would be difficult. However, the sign and approximate magnitude of the e.m.f.'s would be of considerable value.

Note that the induced e.m.f. increases as the probes are placed close to the contact. In an arrangement of contacts such as one finds in the transistor, sizable effects may be expected if one measures the e.m.f. induced between the emitter and the collector while current is passed from one of them to the base. In this case, however, there will be a large unbalance voltage before application of the magnetic field which is canceled for the most part when two pick-up probes are used.

Preliminary trials have shown that a Hall e.m.f. is easily observable in germanium and that reversals in sign may occur as the current through the contact is increased.

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[1] For example, detailed analyses for bulk germanium semiconductors have been made by K. Lark-Horovitz *et al.*—N.D.R.C. Report No. 14-585 (1945); Phys. Rev. **69**, 258 (1946).

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## Nuclear Spin of $Fe^{57}$

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May 19, 1949

THE spectrogram of a 29 milligram sample of iron enriched in the isotope $Fe^{57}$ was inspected for hyperfine structure. The spectrographic apparatus consisted of a one-meter, flint glass, three prism spectrograph[1] crossed with a Fabry-Perot interferometer. The light source was a liquid-air cooled Schuler tube.[1]

Many of the iron lines observed in the region λ4000A to λ6800A involved states having $J$ values greater than one-half and involving penetrating $s$ electrons.[2] No structure was observable in any of these lines.

The wave number difference which could be resolved in the region of the line λ4071.748($3d^74s\cdot F_2-3d^74p\cdot F_2{}^0$) was estimated to be 0.029 cm$^{-1}$. To avoid overestimating the resolution, the total apparent width on the plate of the line λ4071.748 was assumed to be the actual half-width. Since the lines were intense the apparent full width was probably greater than the actual half-width.

That $Fe^{57}$ has no measureable magnetic moment is not surprising, when one considers that many of the elements whose atomic mass is odd, but whose nuclear charge is even, give the same result.

The $Fe^{57}$ was obtained from the Manhattan District.

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[1] M. Gurevitch, Phys. Rev. **75**, 767 (1949).

[2] H. N. Russell and C. E. Moore, Trans. Am. Phil. Soc. **34**, 113 (1944).

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## Infra-Red Absorption by Homonuclear Diatomic Molecules

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May 19, 1949

WE have recently investigated the absorption spectrum of liquid air in the near infra-red region between 1μ and 12μ. Several absorption bands were observed, the most intense bands being near 4.3μ and 6.4μ. The band near 4.3μ overlaps the atmospheric $CO_2$ band in this region but is somewhat broader than the $CO_2$ band. The band near 6.4μ overlaps the atmospheric water-vapor band with center at 6.26μ but is quite different in shape from the water-vapor band and from the bands in the spectrum of liquid water and ice.

It is rather difficult to account for the intense bands in the liquid air spectrum in terms of $CO_2$ or $H_2O$ dissolved in the liquid air or condensed in the liquid air from atmospheric $CO_2$ and $H_2O$, since the observed absorption is more intense than would be expected from $CO_2$ and $H_2O$ as impurities. However, the observed bands appear at positions where one would expect absorption *if the fundamental vibrations of* $N_2$ *and* $O_2$ *were infra-red active.* The vibrations of $N_2$ and $O_2$ have not been regarded as infra-red-active since these molecules are non-polar and hence transitions between vibrational levels cannot be produced by processes involving ordinary dipole radiation; infra-red absorption has not been reported for gaseous nitrogen or oxygen. However, Raman lines have been observed for $N_2$ and $O_2$; the frequencies of the Raman lines and the corresponding infra-red wave-lengths are as follows:

| Molecule | Observed Raman frequency | Corresponding wave-length* in the infra-red |
|---|---|---|
| $N_2$ | 2330.7 cm$^{-1}$ | 4.2905μ |
| $O_2$ | 1554.7 | 6.4321μ |

Within the present limits of error the wave-lengths calculated from the observed Raman lines coincide with the wave-lengths at which the liquid air bands were observed in the present study.

In order to check the tentative assignment of the observed bands to $N_2$ and $O_2$ further measurements were made on liquid nitrogen and liquid oxygen. In the spectrum of liquid nitrogen, the $4.3\mu$-band was strong but no band was observed near $6.4\mu$. In the spectrum of liquid oxygen, the $6.4\mu$-band was extremely intense and the $4.3\mu$-band was weak; the weak $4.3\mu$-band could be attributed to nitrogen, which was present in a concentration of 10–15 percent as an impurity. These results are in agreement with the assumption that the $4.3\mu$-band is due to the fundamental vibration of $N_2$ and the $6.4\mu$-band to the fundamental vibration of $O_2$.

Concerning the processes involved in absorption by $N_2$ and $O_2$, we might mention several possibilities. First, there are quadrupole-radiation processes which are possible for homonuclear molecules. Quadrupole radiation would account for weak absorption by $N_2$ and $O_2$ in both gaseous and liquid states; there is no *a priori* reason for expecting a marked increase in absorption when liquefaction takes place. Second, there is the possibility of "enforced dipole radiation," which results from dipole moments induced during collisions between molecules; absorption by this process would be much greater in the liquid than in the gas. In the case of $O_2$, there is the possibility of magnetic dipole radiation, since $O_2$ has a large magnetic dipole moment. Finally, there is the possibility that the molecules in the liquid are actually associated as definite polymers which could absorb by dipole-radiation processes. From the work done thus far, it is impossible to ascertain the relative importance of these possible radiative processes in the observed absorption. The work on liquids is being continued, and it is possible that further studies of other absorption bands observed at shorter wave-lengths will yield valuable information.

It might be pointed out that the fact that the close proximity of the $N_2$ and $O_2$ bands to the strong atmospheric absorption bands of $CO_2$ and $H_2O$ may have masked weak absorption bands which may be produced by $N_2$ and $O_2$ in the gaseous state. Studies of the infra-red absorption of dry oxygen and $CO_2$-free nitrogen gas are planned for the near future.

We wish to thank Professor H. H. Nielsen for his interest and encouragement and Professors R. A. Oetjen and E. E. Bell for making the infra-red equipment available to us.

* The infra-red positions calculated from band-head measurements are $4.238\mu$ for $N_2$ and $6.327\mu$ for $O_2$.

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## Dependence of Resistivity of Germanium on Electric Field*

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May 16, 1949

We have previously reported experiments[1,2] which were originally designed to explain the anomalously low spreading resistance of high back voltage germanium rectifiers. These experiments showed that the resistance of high resistivity ($\rho \gtrsim 1$ ohm-cm) germanium samples is reduced when high field strength pulses are applied. Most of the experiments were carried out with constant current pulses (five microseconds long, with a repetition rate of 60/sec.) applied through soldered contacts to rectangular blocks of germanium, one to five millimeters long. The pulses were observed and measured on an oscilloscope. The experimental arrangement is illustrated in Fig. 1. At fields of the order of 100 volts/cm and even less, appreciable decreases in resistance were obtained. The changes in resistance lagged behind the voltage, producing a delay of one or more microseconds before equilibrium could be obtained.

Subsequent experiments at the Bell Telephone Laboratories[3] indicated that holes are injected into the $N$-type material from the positive metal contact, and that the holes are drawn into the material by the electric field, thereby increasing the carrier concentration and decreasing the resistance. The lag in the resistance changes may be explained by the transit time of the injected holes, which move with a mobility estimated by Haynes and Shockley[4] to be 1200 cm$^2$/volt sec.

This interpretation is also consistent with Hall effect and resistance-temperature dependence measurements made at high field.

Hall effect measurements were made, utilizing the high field pulse technique. Because of the large current densities, measurable Hall e.m.f. pulses of the order of one volt were obtained across soldered Hall probes in a transverse magnetic field, $H = 4600$ gauss. The Hall constant was found to decrease rapidly with electric field strength, thus corroborating the idea of an increase in concentration of carriers by the high electric field.

The temperature dependence of the conductivity $\sigma$ was studied at various electric fields across the sample. In Fig. 2 are shown curves of this dependence. From these curves, the temperature dependence of the changes in conductivity at a given field, $\Delta\sigma$, can be calculated. $\Delta\sigma$ is found to increase with rising temperature in the impurity conduction range, but decrease with temperature in the transition to intrinsic conduction. To interpret the temperature measurements both the injection and transmission of the carriers have to be considered. Low voltage Hall and resistivity curves on the same samples showed that in the impurity range the mobility varied as $T^{-\frac{3}{2}}$ and the concentration of carriers was nearly constant down to about 140° absolute. We would expect that as the temperature rises and mobility decreases, the transmission of the injected carriers at a given field would decrease, and consequently $\Delta\sigma$ would become smaller. Since $\Delta\sigma$ actually increases in the impurity range, it appears that the injection rate increases with $T$, and that this increase more than compensates for the decrease in mobility. The decrease of $\Delta\sigma$ with rising temperature in the transition range may be due to a decrease in the lifetime of the injected carriers as the concentration of the holes and electrons becomes high, or a decrease in injection rate if the barrier height for hole injection has increased.

Very similar effects are obtained in $P$-type germanium[2] with high field strength pulses. Specifically, a decrease in resistance which lags behind the voltage, a decrease in Hall constant with electric field, and qualitatively similar temperature dependence of $\Delta\sigma$, (see Fig. 2) were all found. Further experiments showed that

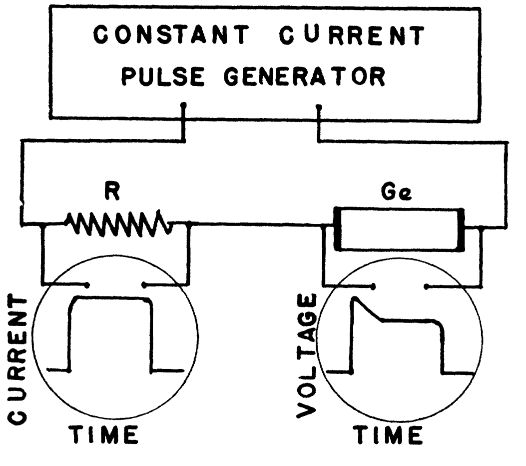

FIG. 1. Schematic illustration of experimental arrangement and of current and voltage pulses for a block of germanium.