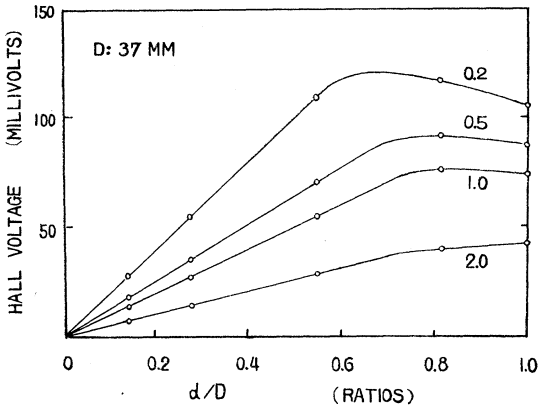

FIG. 3. Hall voltage *vs* fractional distance (d/D) for various values of the tube current (0.2, 0.5, 1.0, and 2.0 amperes), where d is distance between the probes and D is the tube diameter (37 mm). The tube contains argon at a pressure of 2 mm Hg. The magnetic field is 2 gauss.

An experiment with a tube of inside diameter 22 mm indicated that in the second region the Hall voltage was changed through zero to a negative value.

The variation of the Hall voltage with magnetic field strength in the second and third regions is shown in Fig. 2. The Hall voltage is exactly proportional to the magnetic field strength in the third region. However, in the second region deviations appear for magnetic fields greater than several gauss.

Another tube was prepared with five double probes, and the relation between Hall voltage and distance between probes was studied; the results are shown in Fig. 3. The abscissa is the ratio of the distance between probes to the tube diameter, and the parameter is the tube current in amperes. The Hall voltage was nearly proportional to the distance between the probes when these were placed near the tube axis.

To a first approximation, if we neglect the effect of ion current, the observed value of Hall voltage (V_0) is expressed by

$$V_0=\frac{kT}{e}\log\frac{n_2}{n_1}-\frac{vHd}{c},$$

where e, T, and k are electron charge, electron temperature, and Boltzmann's constant; c, v, H, and d are the velocity of light, the electron drift velocity, the magnetic field strength, and the distance between the probes respectively; n_1 and n_2 are the random plasma densities at probe 1 and probe 2. Here, the ratio of n_2 to n_1 depends not only on H, but also on the tube current. V_0 is considered to be composed of the diffusion term[1] and the ordinary Hall term. Under the usual experimental conditions, the diffusion term is large compared with the ordinary Hall term, because the electron temperature is very high and the magnetic field is weak. This was verified by the fact that the value of $(kT/e)\log(n_2/n_1)$ calculated from the characteristic curves[2] of the double probe agreed approximately with the observed voltage. The measurement of Hall voltage seems to be a valuable method for studying the positive column.

The authors wish to express their thanks to Professor S. Kojima for discussions during the course of the investigation.

[1] R. Landauer and J. Swanson, Phys. Rev. **91**, 555 (1953).
[2] S. Kojima and K. Takayama, J. Phys. Soc. (Japan) **5**, 357 (1950).

Alignment of Sodium Atoms*

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IN the course of work on the polarization of sodium atoms by the absorption of circularly polarized resonance radiation,[1] observations were also made with the incident light unpolarized. An effect was observed which is interpreted as a partial alignment induced in the sodium by the scattering of the unpolarized photons. Because of the definite direction of incidence, the unpolarized photons possess some order, and the scattering of such photons induces alignment along the axis of the incident light. The alignment of the sodium affects the polarization ratio $(\sigma-\pi)/(\sigma+\pi)$ of the light scattered at 90°. In Fig. 1 the measured shift in this

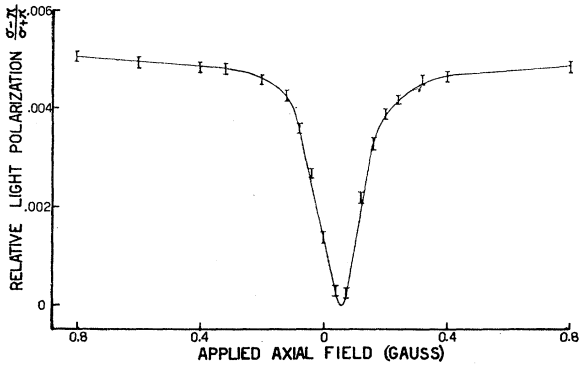

FIG. 1. Polarization ratio of the scattered resonance radiation with incident radiation unpolarized.

polarization ratio is plotted against the magnetic field strength applied along the direction of the incident light. The total magnetic field in the two other directions was made as nearly as possible zero by the use of compensating Helmholtz coils. The corresponding plot with the incident radiation circularly polarized differs mainly in the scale of the ordinate, and its features have been described previously.[1] The asymmetry previously observed has been removed by the use of more nearly homogeneous magnetic fields.

From Fig. 1, the polarization ratio of the scattered light for sodium in thermal equilibrium occurs for an applied field of 0.055 gauss, for which the axial com-

ponent of the earth's field is compensated. The resulting residual transverse magnetic field causes a spin precession after a first scattered photon which serves to destroy essentially all alignment and to restore thermal equilibrium before a second photon can be scattered. At values of the applied axial field far from 0.055 gauss, atoms are not restored to thermal equilibrium after scattering a photon and may scatter a second photon while in this non-equilibrium state. The polarization ratio of this second scattered photon is computed to be larger than that of the first photon scattered, in agreement with the experimental observations. The total observed shift in light polarization ratio should depend on the intensity of the light source, since this determines the number of atoms which scatter more than one photon. As expected, it is found experimentally that for the range of light intensity available, the shift in polarization ratio is in direct proportion to the intensity of the incident light. With the maximum intensity available, a shift of 0.0034 is calculated; the observed value is 0.0048, indicating that the incident light may not be completely unpolarized.

The alignment of sodium by the scattering of unpolarized light may be understood from reference 1, considering the unpolarized light as composed of equal numbers of right and left circularly polarized photons. In Table I of reference 1, it may be noted that the $m_F=0$ populations are reduced by the scattering of a circularly polarized photon independent of the rotational sense. Consequently, the scattering of an unpolarized photon will reduce the $m_F=0$ state populations relative to those with $|m_F|=F$, the condition of alignment. For two scattered photons there are atoms which scatter photons of the same polarization and contribute to the alignment of the ensemble and atoms which scatter oppositely polarized photons and do not contribute significantly. For more than two photons the process does not proceed to complete alignment but reaches an equilibrium partial alignment, for the effect of unpolarized resonance radiation on a completely aligned ensemble is to reduce the alignment.

TABLE I. Occupation numbers of atoms which have scattered n unpolarized photons, $n=\infty$ corresponding to the equilibrium state. P_1 and P_2 are the total numbers of atoms in the two hyperfine states. R_n is the polarization ratio of the nth scattered photon.

	$F=1$			$F=2$		P_1	P_2	R_n
n $m_F=$	±1	0	±2	±1	0			
0	0.125	0.125	0.125	0.125	0.125	0.375	0.625	...
1	0.128	0.119	0.144	0.115	0.106	0.375	0.625	0.0700
2	0.128	0.116	0.154	0.110	0.100	0.372	0.628	0.0905
3	0.126	0.115	0.161	0.108	0.099	0.367	0.637	0.0997
∞	0.125	0.115	0.163	0.106	0.098	0.365	0.636	

Table I gives the probability of an atom being in various states having the quantum numbers F, m_F (total angular momentum, magnetic quantum number) after having scattered one, two, or three photons, as well as the values at equilibrium. Although the approach to equilibrium is fairly rapid, the equilibrium alignment is seen to be small. The difference in populations of corresponding magnetic substates of the two hyperfine levels at equilibrium, although small, is many times that in thermal equilibrium at room temperature due to the energy separation.

There is no reason to believe that the effect should be confined to sodium, since the argument given for the production of alignment is quite general. It must be understood, however, that the argument applies only to light incident from a restricted part of a sphere; for isotropic unpolarized light defines no axis with respect to which alignment can take place.

I wish to thank Dr. R. H. Dicke for helpful discussion and criticism.

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[1] W. B. Hawkins and R. H. Dicke, Phys. Rev. **91**, 1008 (1953).

Photovoltaic Effect in Cadmium Sulfide

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DURING the course of a recent investigation with the photoconduction and rectification properties of CdS crystals, a pronounced photovoltaic effect was observed. The crystals used for this investigation were grown from the vapor phase by a technique previously reported.[1]

The rectification studies were conducted on crystals using an indium base electrode and such metals as silver, copper, gold, and platinum as counter electrodes. It was in some of these rectifiers that pronounced photovoltaic effects were observed.

The photovoltaic cells that have been tested to date have been made by applying the base electrode and counter electrode on opposite faces of a CdS crystal approximately 3 mm thick. Light more or less parallel to the electrodes was then applied to the open face of the crystal. From this arrangement open-circuit voltages of 0.4 v have been measured in direct sunlight and 0.6 v in focused sunlight. Short-circuit currents of 15 ma cm^{-2} have been measured in direct sunlight and 300 ma cm^{-2} in focused sunlight. The photovoltaic effect has also been observed in pellets of CdS powder (pressed and fired); however, the current obtained from these cells is less than that obtained from a single crystal as expected. Work is currently being carried out to prepare a semitransparent electrode on one face so that crystals can be illuminated perpendicular to the face.