THE POLARIZATION OF MERCURY RESONANCE RADIATION

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(Received December 9, 1931)

Abstract

The polarization of the line λ2537A of mercury in resonance radiation is calculated on the assumption that isotopes 199 and 201 have nuclear moments of 1/2 and 3/2 respectively, while the even isotopes 198, 200, 202, and 204 have zero nuclear moment as Schüler and Keyston have suggested. With "broad line" and "narrow line" sources respectively, resonance radiation excited by light polarized with the electric vector parallel to the magnetic field should be 84.7 percent and 88.7 percent polarized, in fair agreement with the observations of Olson, 79 to 86 percent, and von Keussler, 79.5 percent. Relative transition probabilities within a hyperfine multiplet are calculated on the assumption of *LJS* type coupling between *J*, *F* and *I*.

Ellett and MacNair[1] have shown that the incomplete polarization of the line λ2537A of mercury in resonance radiation is due to the peculiar behavior of the −25.6 and +22.1 mA hyperfine structure components in a magnetic field. Previously MacNair[2] had shown that the parallel Zeeman component of the −25.6 hyperfine structure line shifts toward longer wavelengths with increasing field.

Recently Schüler and Keyston[3] have proposed an explanation of the hyperfine structure of this line, assigning nuclear moments of 1/2 and 3/2 to isotopes 199 and 201 respectively, and zero nuclear moment to the even isotopes. According to this proposal the components due to the even isotopes 198, 200, 202, 204, occur at −10.3, 0.00, +11.6, +22.1 mA respectively. The stronger component of isotope 199 is located at −25.6 and the weaker at +22.6, placing the center of gravity of the 199 pattern midway between −10.3 and 0.00. Since the levels of 201 are inverted, the strongest component of 201 is assigned to +22.1, the next to −10.3, and the weakest to −25.6. This explanation gives the correct positions of all five components and gives relative intensities in fair agreement with the observations of Mrozowski,[4] but in poor agreement with Schrammen's[5] observations. This structure of λ2537 will be used in this paper to calculate the polarization of resonance radiation to be expected.

The method of calculating the polarization is that given by Ellett,[6] based on the assumption that *I* and *J* combine vectorially to a resultant *F* just as *S* and *L* combine in the alkali spectra to the resultant *J*. The selection prin-

[1] Ellett and MacNair, Phys. Rev. **31,** 180 (1928).
[2] MacNair, Proc. Nat. Acad. **13,** 430 (1927).
[3] Schüler and Keyston, Naturwiss. **31,** 676 (1931).
[4] Mrozowski, Nature **127,** 890 (1931).
[5] Schrammen, Ann. d. Physik **83,** 1161 (1927).
[6] Ellett, Phys. Rev. **35,** 588 (1930).

ciple for $F(\Delta F = \pm 1, 0)$ gives the possible hyperfine components, the intensities of which are obtained from formulas given by Hill.[7]

In order to calculate the polarization a hypothetic magnetic field is introduced parallel to the axis of symmetry, the electric vector of the incident plane polarized light in this case. This field is introduced to remove the degeneracy which exists in the absence of any field and must be considered strong enough to separate completely the magnetic energy levels, but still very weak as regards the Paschen-Back effect of the hyperfine structure. Then the principle of spectroscopic stability insures that the polarization so calculated will be the polarization in zero field. The intensities of the Zeeman components, and hence the relative transition probabilities to the various upper magnetic levels, are calculated from the usual Kronig-Hönl formulas, with the use of the quantum numbers appropriate to hyperfine structure.

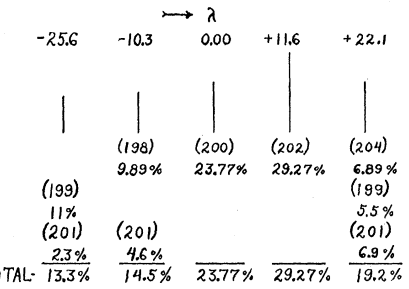


Fig. 1. The hyperfine structure of λ2537 of Hg (after Schüler and Keyston).

Since in this type of excitation only the parallel Zeeman components of the incident radiation are absorbed, the relative populations of the upper levels become equal to the transition probabilities of these parallel components. Having the relative populations we calculate the probabilities of reemission parallel and perpendicular to the magnetic field. The polarization is then given by

$$P_{0/0} = \frac{I_{\parallel} - I_{\perp}}{I_{\parallel} + I_{\perp}} 100$$

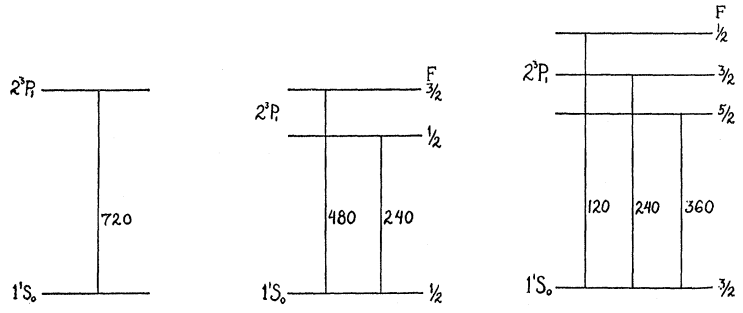
The intensity distribution in the resonance radiation depends upon the relative numbers of atoms present in the resonance lamp and upon the intensity distribution in the exciting radiation. That is, the relative intensity of each Zeeman component in the resonance radiation is proportional to the relative number of atoms of the isotope to whose hyperfine structure pattern it belongs and is also proportional to the relative intensity of that hyperfine structure component in the source which is effective in exciting the initial magnetic level on which this Zeeman component originates.

In order to have sufficient intensity in the resonance radiation, the source of excitation is usually run at such a temperature that the density of mercury vapor is high enough to cause considerable self reversal. The effect of self re-

[7] Hill, Proc. Nat. Acad. **15**, 779 (1929).

versal, being greater the more intense the line, tends to equalize the intensities in the source so that the intensity distribution is sensibly uniform across the entire hyperfine pattern. In this case, that of "broad line" excitation, the intensities in the resonance radiation will depend only on the relative abundance of isotopes in the resonance bulb.

However, if the source is run at a temperature such that the density of mercury vapor is low enough to eliminate self-reversal, then the intensity in



Figs. 2a, 3a, 4a. Hyperfine structure components of even isotopes, isotope 199, and isotope 201, respectively.

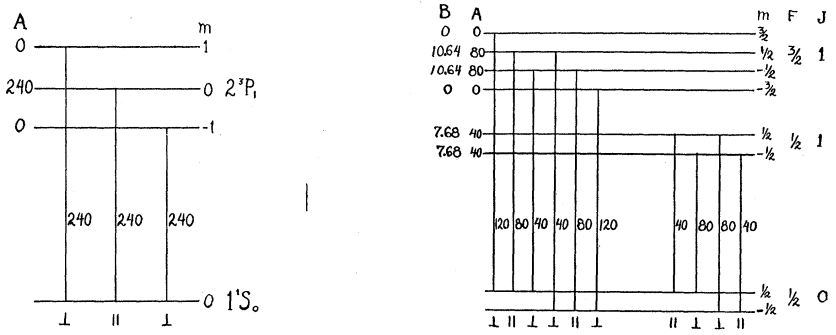


Fig. 2b. Transition probabilities and relative populations for the even isotopes, for "broad line" excitation.

Fig. 3b. Transition probabilities and relative populations for isotope 199. Column *A* gives populations for "broad line" excitation, column *B* for "narrow line" excitation.

the source is distributed across the hyperfine pattern according to the theoretical distribution and the total intensity of each Zeeman component emitted in resonance radiation will be proportional to the intensity of the hyperfine component exciting it. The theoretical intensity distribution in the source operating under these conditions is shown in Fig. 1, (after Schüler and Keyston).

The hyperfine patterns for the three types of isotopes, the even isotopes with $I=0$, the isotope 199 with $I=1/2$, and the isotope 201 with $I=3/2$, are given in Figs. 2a, 3a, and 4a, respectively, with the appropriate a priori in-

tensity written on each component. Figs. 2b, 3b, and 4b give the corresponding Zeeman patterns for the above hyperfine patterns, with the transition probability given beside each component.

At the left of the three latter diagrams, in columns A and B, are given the relative populations of the upper levels for the "broad line" and "narrow line" sources, respectively. (These populations are for equal numbers of atoms of the different isotopes in the resonance lamp and must be multiplied by the relative abundance to get the true "populations".) These populations for "narrow line" source are not tabulated for the even isotopes since the values will be different for each of these.

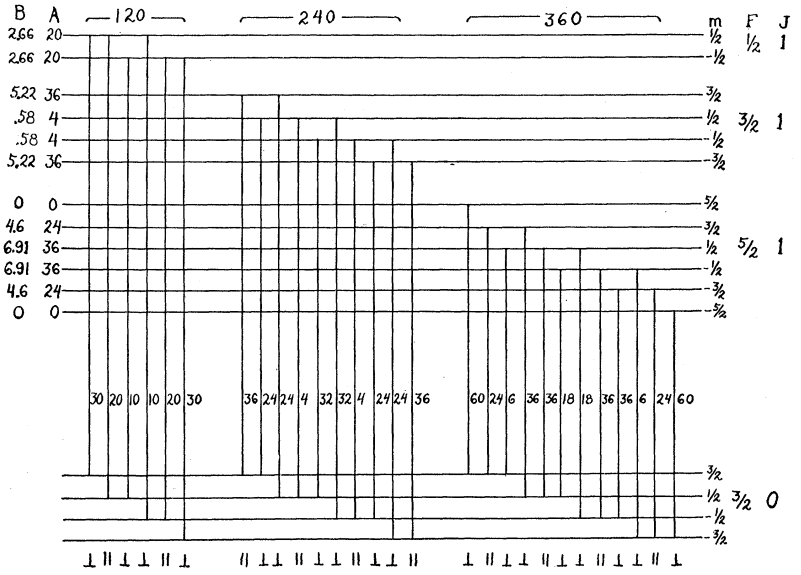


Fig. 4b. Transition probabilities and relative populations for isotope 201.

The results of the calculations are given in Table I.

TABLE I.

Excitation	Polarization ($E\|H$)
"Broad line"	84.7 percent
"Narrow line"	88.7 percent

COMPARISON WITH EXPERIMENT

Olson[8] found that the polarization of the line in zero field was dependent somewhat upon the conditions of the source. With a water-cooled quartz-mercury arc operating on 3.5 amperes, he obtained 79 percent initial polarization. The same arc operated on 1 ampere gave 84 percent, and with 0.4

[8] Olson, Phys. Rev. **32**, 443 (1928).

ampere arc current gave 86 percent polarization in zero field. Von Keussler[9] obtained 79.5 percent for the initial polarization.

These observed values for the initial polarization lie within the range from "broad line" source to "narrow line" source. The agreement between the polarizations calculated on the basis of Schüler's[3] explanation and the experimental values is fair.

[9] Von Keussler, Phys. Zeits. **27,** 313 (1926).