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Authors
Church, D.A.
Hadeishi, T.
McLaughlin, R.D.
et al.

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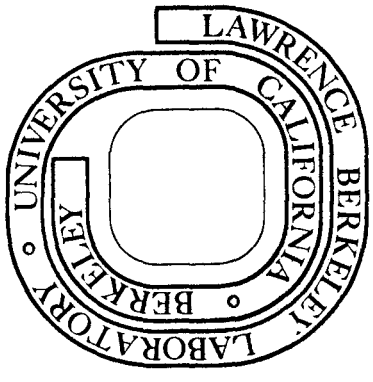

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COHERENT FORWARD SCATTERING AS A SENSITIVE MEANS FOR TRACE ELEMENT DETECTION*

D. A. Church, T. Hadeishi, R. D. McLaughlin, and B. D. Zak
University of California
Lawrence Berkeley Laboratory
Berkeley, California 94720

Coherence effects observed as a function of magnetic field strength in polarized optical resonance radiation scattered in the forward direction are similar to those observed in laterally scattered light.[1] However, in the forward direction, the scattered light is itself coherent, giving rise to line-broadening and coherence in the light emitted by different atoms, which are not otherwise observed.[1,2]

Figure 1 shows the apparatus used to observe the forward scattered light. The light source consists of a quartz mercury resonance lamp, containing a single isotope, excited by a radio-frequency oscillator. When the lamp is placed in a strong magnetic field, the Zeeman effect of the excited ($^3P_1$) level splits the resonance line into three components, which are distinguished by their polarization and angular distribution. In the configuration shown, right- and left-circularly polarized components are separated by a small magnetic-field-dependent frequency from the zero-field transition near 2537 Å. By adjusting the field on the lamp, these spectral components can be tuned in frequency (Zeeman scanning[3]). When these circularly polarized components pass through the quarter-wave plate, they become linearly polarized in orthoganal directions. One component passed through the linear polarizer and is scattered by the atoms in the cell; the other component is blocked. Some of the forward scattered radiation can pass the second polarizer, which is oriented to block non-scattered light. Consequently, the scattered light signal

appears with no background. When a magnetic field is applied to atoms in the cell, a "line-crossing"[2] occurs, which is a variation of the intensity of forward scattered light with magnetic field strength. The light intensity reaches a minimum when the Zeeman levels of the excited state of the scattering atoms cross; for instance about zero field strength. When the scattering atoms are in vacuum, the line-shape of the crossing is Gaussian, but in air at atmospheric pressure the line-shape becomes Lorentzian.[4] Figure 2 shows the line-crossing curve for natural mercury in 1 atmosphere of nitrogen (Lorentzian shape). The collisions with the nitrogen molecules broaden the line-crossing considerably, but substantial scattered light intensities are observed at modest field strengths. By Zeeman scanning the lamp, it was possible to find the optimum wavelength for the incident light to produce the maximum forward scattered signal. This wavelength was found to be near the unshifted wavelength of the mercury isotope 198; such lamps were then used in subsequent measurements.

The same apparatus was used to detect small concentrations of mercury in air by replacing the closed cell with an open absorption tube, having a side arm serving as an expansion chamber. A sample of air containing mercury vapor, taken with a syringe from a tube containing a small pool of mercury at room temperature, was injected into the expansion chamber, and blown into the absorption tube by a constant flow of carrier gas. The density of atoms in the absorption tube under these conditions is given by[5]

$$\frac{N(t)}{V_A} = \frac{N_0}{(V_0 - V_A)} \left[e^{-Rt/V_0} - e^{-Rt/V_A} \right]$$

where N_0 is the initial atom number, R is the carrier gas flow rate, and V_A and V_O are respectively the volumes of the absorption tube and the expansion chamber. With this arrangement, it was also possible to simultaneously inject a strong interference absorber, such as benzene vapor. Absorption signals for mercury vapor and benzene vapor in air are shown in Figure 3(a); they were made with the same apparatus with zero field strength applied to both the lamp and the atoms in the absorption region, and with the final (analyzing) polarizer removed. Figure 3(b) shows the corresponding forward scattered light signals from a small volume of mercury vapor alone, and also with benzene interference. The absorption length was 12 cm, and the magnetic field strength near 4 kG. It can be seen that even substantial relative interference can be tolerated, and that minute densities of mercury (in this case near 1 $\mu gr/m^3$) can be observed. Due to the coherence of the scattered light, the observed signal is proportional to the square of the length L of the absorption region. An increase in this length by a factor of 5 has given a detection sensitivity well in excess of the proposed Federal guideline for ambient air.

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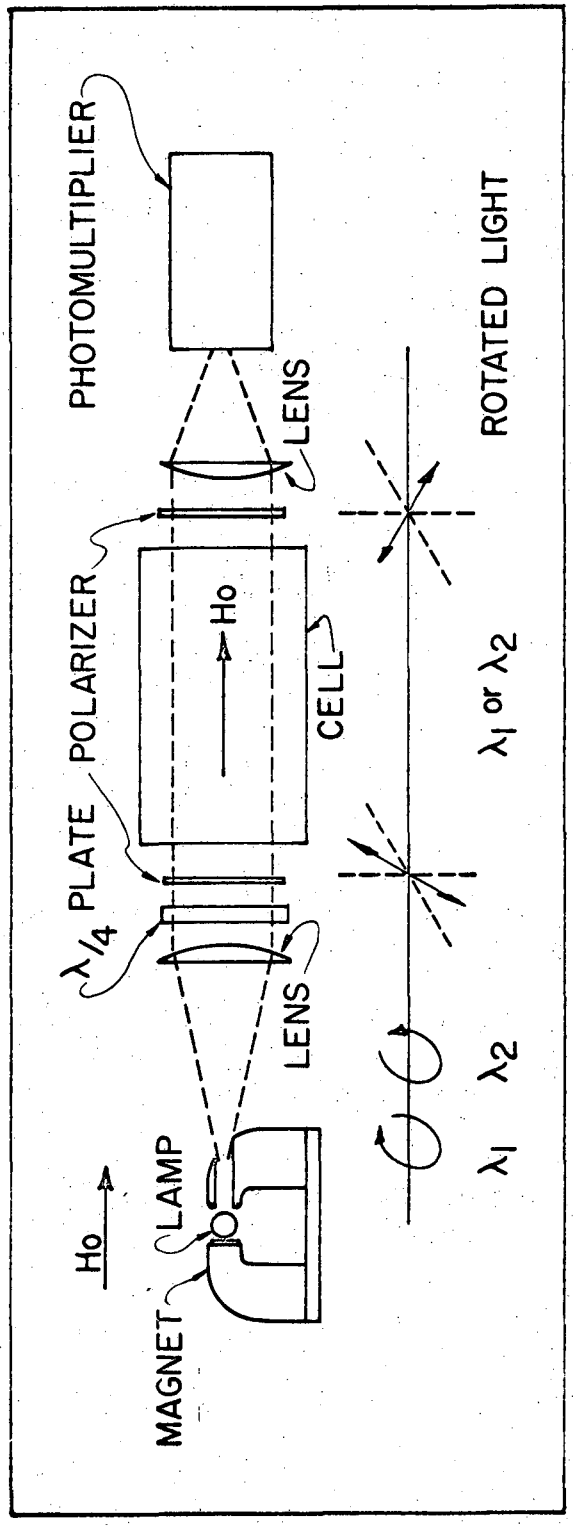

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FIGURE 1

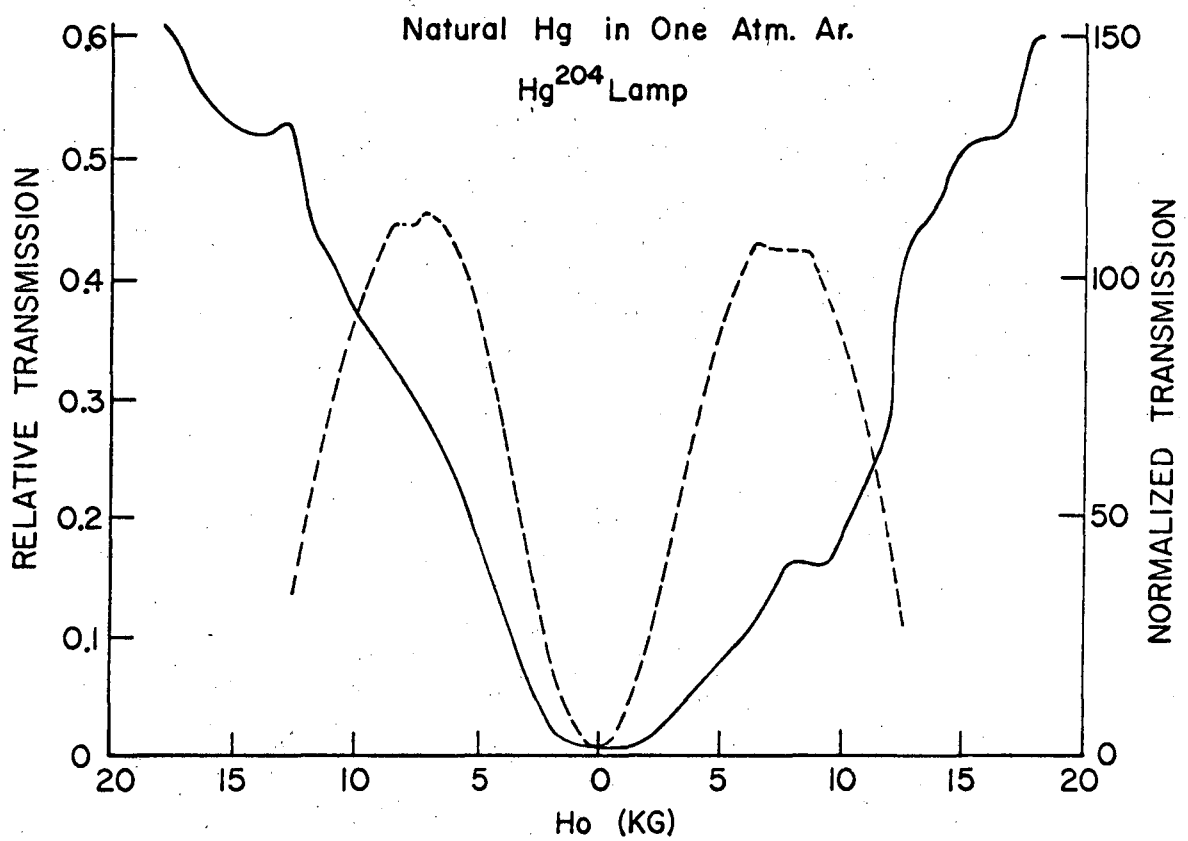

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FIGURE 2

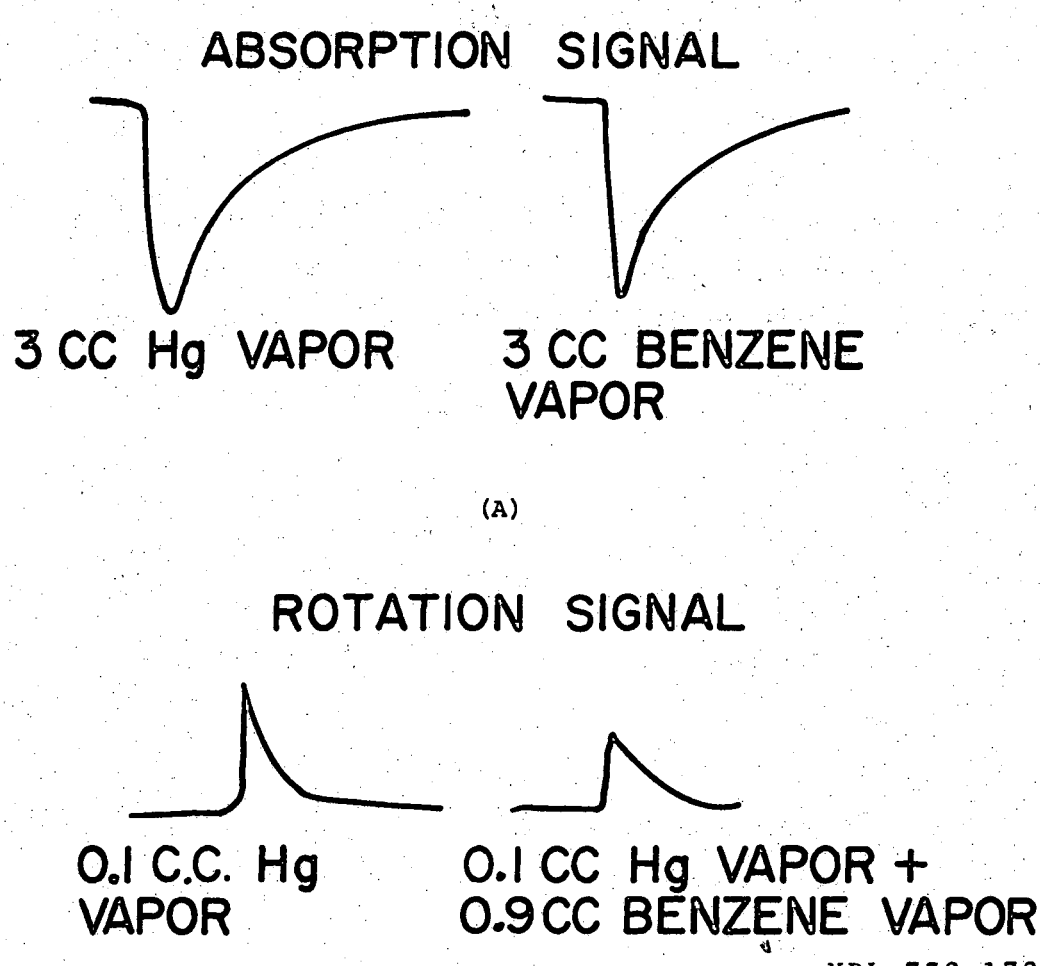
ABSORPTION SIGNAL
3 CC Hg VAPOR
3 CC BENZENE VAPOR
(A)
ROTATION SIGNAL
0.1 C.C. Hg VAPOR
0.1 CC Hg VAPOR + 0.9 CC BENZENE VAPOR
XBL 732-172
(B)

FIGURE 3

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