

the results of the theory will be published elsewhere. It is found that the accuracy in setting of the two mirrors is of the same order as that required in a double crystal spectrometer.

I am grateful to Mr. S. Ramaseshan and Mr. G. Suryan for the discussions I had with them on this subject.

¹ W. Ehrenberg, *Nature* **160**, 330 (1947).

² P. Kirkpatrick and A. V. Baez, *J. Opt. Soc. Am.* **38**, 766 (1948).

³ C. M. Lucht and D. Harker, *Rev. Sci. Instr.* **22**, 392 (1951).

⁴ S. Timoshenko, *Theory of Plates and Shells* (McGraw-Hill Book Company, Inc., New York, 1940).

Antiproton Annihilation*

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THE cross section for meson production by proton-antiproton annihilation was calculated by the usual second-order perturbation procedure. The results for neutral s.-s. (scalar theory with scalar coupling), charged s.-s., neutral p.s.-p.s., and charged p.s.-p.s. are in agreement with those of Ashkin, Auerbach, and Marshak.¹ Results for the other cases are given in Tables I and II for the center-of-mass system in units of $\hbar=1$, $c=1$, for the limit

TABLE I. Total and differential meson production cross sections for the limit $p \rightarrow 0$.

Interaction	Total cross section $p \rightarrow 0$	Differential cross section $p \rightarrow 0$
neutral p.s.-p.v.	$\frac{4}{3\pi} \frac{g^4 K}{\mu^4} p$	$\frac{g^4 K}{2\pi^2 \mu^4} p \sin^2 \theta$
charged p.s.-p.v.	$\frac{g^4}{8\pi} \left(\frac{K}{\mu}\right)^4 \frac{1}{Kp}$	isotropic
neutral v.-v.	$\frac{g^4}{144\pi} \frac{1}{Kp}$	isotropic
charged v.-v.	$\frac{g^4}{72\pi} \left(1 + \frac{9}{2} \frac{\mu^2}{K^2}\right) \left(\frac{K}{\mu}\right)^4 \frac{1}{Kp}$	isotropic
neutral p.v.-p.v.	$\frac{g^4}{144\pi} \frac{1}{Kp}$	isotropic
charged p.v.-p.v.	$\frac{g^4}{72\pi} \left(1 + \frac{3}{2} \frac{\mu^2}{K^2}\right) \left(\frac{K}{\mu}\right)^4 \frac{1}{Kp}$	isotropic

TABLE II. Total and differential meson production cross sections for the limit $p \rightarrow \infty$.

Interaction	Total cross section $p \rightarrow \infty$ Extreme rel. limit	Differential cross section $p \rightarrow \infty$ Extreme rel. limit
neutral p.s.-p.v.	$\frac{g^4 K^2}{\pi \mu^4} \left(2 + \frac{K^2}{p^2} \ln \frac{4p^2}{K^2}\right)$	$\frac{g^4 K^2}{2\pi^2 \mu^4} \left(1 + \frac{4K^2 p^2}{A}\right)$
charged p.s.-p.v.	$\frac{g^4}{12\pi} \frac{p^2}{\mu^4}$	$\frac{g^4}{32\pi^2} \frac{p^2}{\mu^4} \sin^2 \theta$
neutral v.-v.	$\frac{g^4}{144\pi p^2} \left(\ln \frac{4p^2}{K^2} - 1\right)$	$\frac{g^4}{64\pi^2} \left(\frac{8p^2}{9A} - \frac{1}{9p^2}\right)$
charged v.-v.	$\frac{g^4}{108\pi} \frac{p^2}{\mu^4}$	$\frac{g^4}{288\pi^2} \frac{p^2}{\mu^4} \sin^2 \theta$
neutral p.v.-p.v.	$\frac{g^4 K^2}{36\pi \mu^4} \left(2 - \frac{K^2}{p^2} \ln \frac{4p^2}{K^2}\right)$	$\frac{g^4 K^2}{72\pi^2 \mu^4} \left(1 - \frac{4K^2 p^2}{A}\right)$
charged p.v.-p.v.	$\frac{g^4}{108\pi} \frac{p^2}{\mu^4}$	$\frac{g^4}{288\pi^2} \frac{p^2}{\mu^4} \sin^2 \theta$

of $p \rightarrow 0$ (p =nucleon momentum) and $p \rightarrow \infty$ (extreme relativistic limit, nucleon energy greater than five times nucleon rest mass). K =nucleon mass; μ =meson mass; θ =angle between proton and positive meson for charged cases, angle between proton and neutral meson for neutral cases

$$A = (2p^2 + 2K^2 - \mu^2)^2 - 4p^2(p^2 + K^2 - \mu^2) \cos^2 \theta.$$

This problem was suggested by discussions with Professor J. G. Retallack. The author thanks Professor J. V. Lepore for many helpful discussions on this calculation.

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¹ Ashkin, Auerbach, and Marshak, *Phys. Rev.* **79**, 266 (1950).

Anisotropy in Paramagnetic Resonance Absorption of Picryl-*n*-Amino Carbazyl*

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WE have examined the paramagnetic resonance of a new free organic radical, picryl-*n*-amino carbazyl. A report on its synthesis will appear in print shortly. From arguments based upon its molecular structure, it was expected that its absorption line would be considerably narrower than that of α, α -diphenyl- β -picryl hydrazyl as a result of stronger exchange effect.

The observations were made using a K -band cylindrical cavity operated in the TE_{01} mode with the cavity axis normal to the applied magnetic field. The specimen was cemented to the end of a quartz rod which protruded along the axis of the cavity to its midpoint. The specimen could then be rotated easily about the cavity axis. The absorption lines were observed by sweeping the magnetic field while the frequency was kept constant. The sensitivity was such that a sample of 5×10^{-6} cm³ carbazyl could produce a good trace on the oscilloscope.

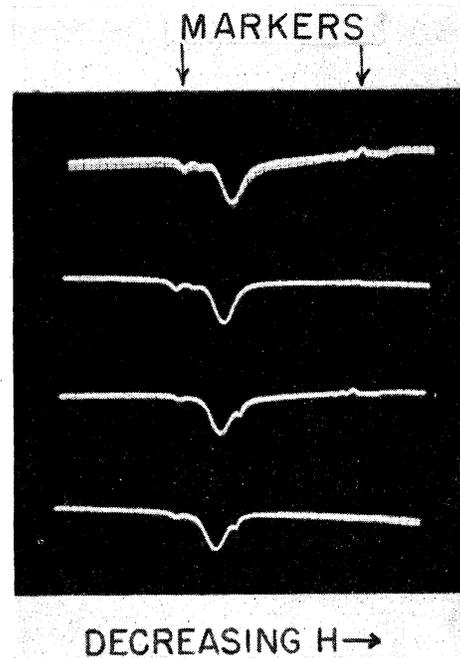


FIG. 1. Carbazyl and hydrazyl samples, showing shift of carbazyl peak with rotation.

For a sample which obviously consisted of several crystals the line width was approximately 7 gauss. This line showed a marked structure, in which the components shifted rapidly as the sample was rotated. Going to a much smaller sample, the spectrum was found to consist of a few clearly resolved lines, each approxi-

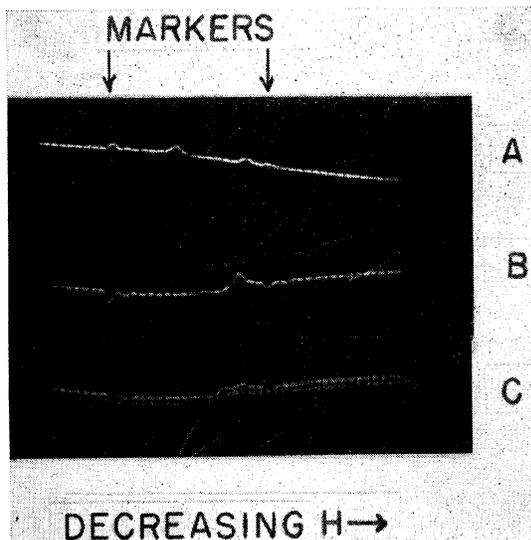


FIG. 2. Absorption spectrum of carbazyl showing two lines, one of which is independent and the other dependent upon orientation. (a) Two peaks slightly separated; (b) two peaks in coincidence; (c) rotation 90° from (b).

mately 0.5 gauss wide. The position of the line appears to depend upon the orientation of the crystal varying over a range of 7 gauss upon rotating the sample through 90° .

The g value of the carbazyl was measured relative to that of the hydrazyl. For this purpose a small polycrystalline specimen of the hydrazyl was also mounted on the quartz rod. As the quartz rod was rotated (see Fig. 1), the hydrazyl peak remained station-

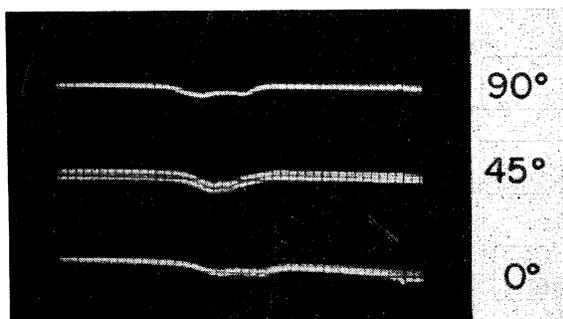


FIG. 3. Hydrazyl lines observed for three orientations. (a) Arbitrary reference; (b) 45° ; (c) 90° .

ary, while the carbazyl peak varied from 5 gauss above to 2 gauss below the hydrazyl peak, corresponding to the effective g -values 2.0024 and 2.0041 respectively, assuming the value of 2.0036 for hydrazyl.¹

Our results indicate that the angular dependence of the resonance peak depends upon the orientation of the crystalline axes. In one sample (see Fig. 2), the absorption spectrum consisted of two lines, one of which showed no directional effect and the other depended strongly on the orientation of the sample. These results

seem to indicate that the observed angular dependence is caused by molecular diamagnetism.

A similar effect was observed for single crystals of hydrazyl² (see Fig. 3). In this case the peak varied over a total range of 5 gauss, or about $\frac{2}{3}$ that of carbazyl.

* Work done under contract with the AEC.

† On leave from Michigan State College, East Lansing, Michigan.

¹ Holden, Kittel, Merritt, and Yager, *Phys. Rev.* **77**, 147 (1950); C. H. Townes and J. Turkevich, *Phys. Rev.* **77**, 148 (1950).

² The sample used in this observation was furnished through the courtesy of Dr. Garstens and Dr. Liebson of the Naval Research Laboratory.

Sublimation and Condensation of Carbon Dioxide, Nitrogen, and Oxygen in an Expansion Chamber*

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THE question of what actually happens in supersaturated water vapor below the freezing point has aroused considerable interest during recent years. A very sensitive experimental method was developed for detecting the presence of the first ice particles in a droplet cloud.¹ (A cloud is formed over a pool of supercooled water, in an expansion chamber precooled below the freezing point. The first ice particle present inoculates the pool and causes it to freeze, the freezing of the pool thus serves as an indicator.) This method allowed a threshold temperature for the appearance of ice (-41.2°C) to be established.

The question then arose as to whether these ice crystals are originated by sublimation or by freezing of minute water droplets. As condensation of water vapor requires considerable supersaturation, a crucial experiment was sought to separate sublimation from condensation, i.e., to observe precipitation in the sublimation temperature region produced by expansion ratios below the threshold values for condensation. The supercooled water pool could not be used here as a detector because the initial supercooling of a chamber has to be in the neighborhood of -40°C , that is, below the temperature region in which supercooled water in bulk can be maintained easily. Therefore observations had to be visual, a rather difficult task, as the showers at best would be very faint in view of the fact that the amount of water available for sublimation in these conditions is small (saturated water vapor pressure at -40°C is 0.0966 mm Hg).

In 1944 Cwilong¹ observed these ice showers with expansion ratios down to 1.07, considerably less than the threshold expansion ratio (1.29 at -40°C) required to produce condensation on negative ions, and therefore concluded that the sublimation is a primary process. In 1948 d'Albe,² using a microscope, failed to see any ice showers using expansion ratios up to 1.1. In 1949 Brewer and Palmer³ reported that in an improved apparatus (details of the work are not published), which eliminates the possibility of cloud contamination by ice splinters from the walls, they did not see any sublimation at all, but just the continuation of C. T. R. Wilson's negative ion threshold for condensation. In 1950 Salmon and Cwilong⁴ repeated the experiments once more, also in an apparatus in which contamination of cloud from the walls is impossible, and in a series of over 300 observations detected genuine sublimation at expansion ratios down to 1.05.

Assuming that sublimation does exist, experimental conditions were sought in which the process could be isolated from condensation and easily demonstrated. Carbon dioxide was thought a suitable cloud-producing substance. High vapor pressure over the solid promised abundant precipitations and a very high vapor pressure of the triple point (3885 cm Hg) excluded the existence of droplets in any cloud which might be formed. Expansions were performed in a chamber precooled to the region of -100°C and containing saturated vapor of CO_2 in a helium atmosphere.

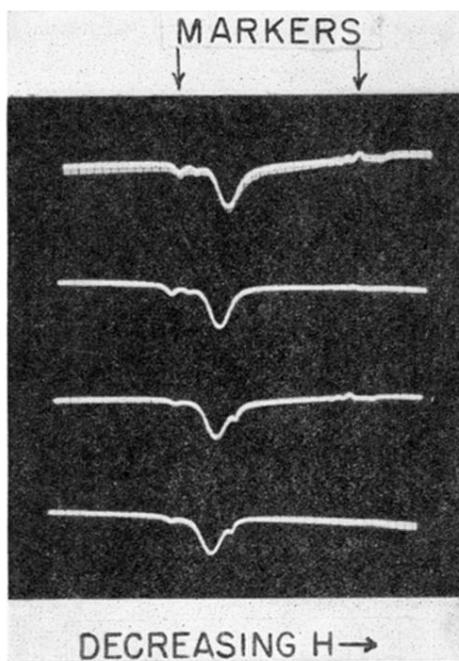


FIG. 1. Carbazyl and hydrazyl samples, showing shift of carbazyl peak with rotation.

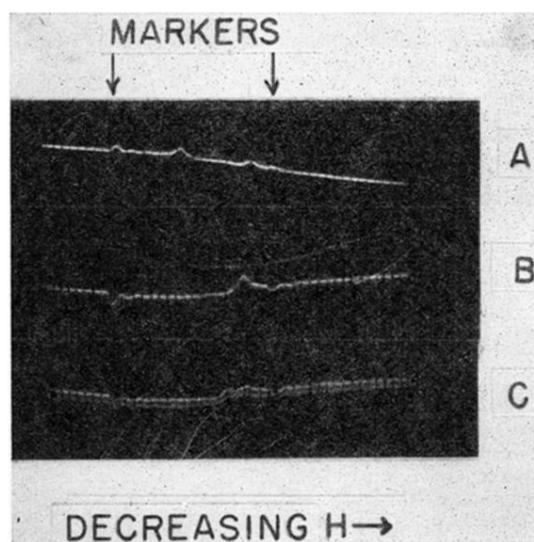


FIG. 2. Absorption spectrum of carbazyl showing two lines, one of which is independent and the other dependent upon orientation. (a) Two peaks slightly separated; (b) two peaks in coincidence; (c) rotation 90° from (b).

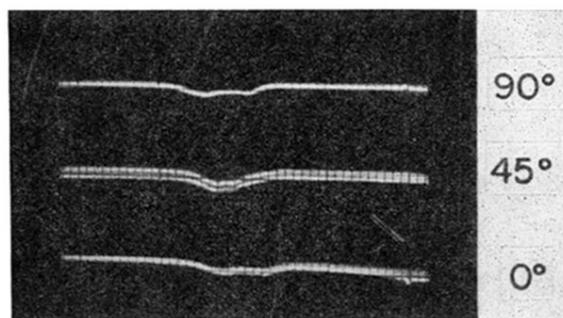


FIG. 3. Hydrazyl lines observed for three orientations.
(a) Arbitrary reference; (b) 45° ; (c) 90° .