Letters to the Editor

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The Dielectric Constant of Liquid Helium

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July 20, 1950

THE dielectric constant of liquid helium was measured at frequencies in the vicinity of 9100 Mc using a transmission-type resonant cavity having a high Q. The resonant frequency of the cavity is measured at liquid helium temperatures from 1.6 to 4.2°K with the cavity evacuated. Then liquid helium is admitted into the cavity through a needle valve arrangement, and the new resonant frequency measured over this range of temperature. The frequency shift at 4.20° is about 220 Mc. Since the cavity resonator is completely filled with helium the dielectric constant is given by the expression

$$K=(f_0/f)^2,$$

where f is the resonant frequency with the dielectric in the cavity, f_0 is the resonant frequency without the dielectric in the cavity, and K is the dielectric constant.

This expression is valid as long as the loss tangent is small. The loss tangent of liquid helium was observed during the course of these measurements to be less than 5×10^{-6}.

The cavity used in this experiment was a cylindrical cavity operating in its lowest mode (TE_{111}) made of cast tin. The normal Q (at 4.2°K) was 40,000 and the Q at 1.9°K 1.5×10^6. This cavity was used because it was available from previous investigations on the high frequency resistance of tin. Precautions were taken to insure that the cavity would be filled with liquid helium. The experiment was carried out in an external Dewar flask filled with liquid helium surrounded by liquid nitrogen. The temperature scale used was the 1937 Leiden scale. The resonant frequency of the cavity was measured by means of a high Q wave meter. The maximum error in the determination of the dielectric constant due to an error in the measurement of frequency is ±0.0005.

A plot of the dielectric constant *vs.* temperature is shown in Fig. 1. Wolfke and Keesom's[1] results of 1928, which were done at a frequency of 500 kc, are also shown. Our values are slightly higher than those of Wolfke and Keesom. They quote an accuracy of ±0.001 in °K. Their value at 4.21°K is 1.048; ours at 4.21°K is 1.0492. The value derived from the optical data at this temperature[2] is 1.0491. The agreement appears to be very good. Also shown is a table (Table I) of the polarization per mole computed from our curve of the dielectric constant over the range of temperatures according to the equation:

$$\alpha=3(K-1)M/4\pi(K+2)P,$$

where M is the mass of helium atom and P is the density. The polarization per mole computed for infinitely long waves by Wolfke and Keesom is 0.1234.

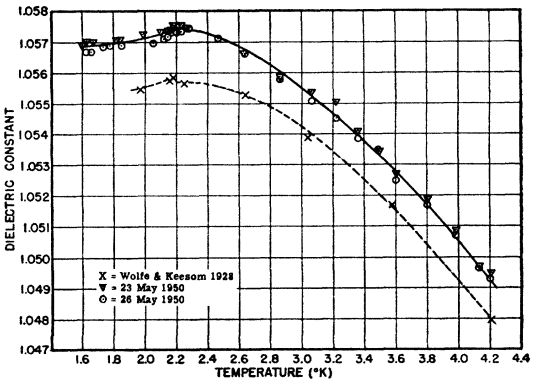

FIG. 1. Dielectric constant of liquid helium.

TABLE I. Dielectric constant and polarization of liquid helium.

Temperature °K	Density[a] g/cm³ ρ	Dielectric constant K	Polarization per mole α
4.21	0.1248	1.0492	0.1236
3.04	0.1405	1.0554	0.1233
2.64	0.1443	1.0568	0.1231
2.25	0.1458	1.0574	0.1231
2.19	0.1458	1.0574	0.1231
1.97	0.1454	1.0571	0.1228
1.62	0.1449	1.0569	0.1228

[a] Densities taken from Table 6.10a, p. 323 of reference 1.

[1] W. H. Keesom, *Helium* (Elsevier Publishing Company, Inc., Amsterdam, 1942), p. 321, paragraph 6.713.
[2] Reference 1, p. 323, paragraph 6.715.

Relativistic Increase in Ionization of Charged Particles in Photographic Emulsions

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August 7, 1950

WE have recently started measurements to ascertain whether any increase in ionization for relativistic, singly charged particles can be detected in photographic emulsions. Preliminary results on the few tracks measured so far indicate that there is a minimum value of the ionization at $E/\mu\sim3$ with an increase of about 10 percent to a constant value (or plateau) at $E/\mu\sim20$ up to very high energies.

The photographic emulsion is a special case where ionization can be measured inside a solid material, and we would expect atomic polarization effects to be important in limiting the distant ionizing collisions, which cause the relativistic increase. The polarization effect was first suggested by Swann[1] and treated quantitatively by Fermi,[2] Halpern and Hall,[3] Wick,[4] and Bohr,[5] their theories giving corrections to be applied to the Bethe-Bloch ionization energy loss formula[6] at relativistic energies. The theories, differing in detail, predict some increase beyond a minimum value to a constant value of ionization energy loss. This limiting value, for a given medium, depends only on the maximum value of energy transfer (η) considered. In the present work η was taken[7] as 10 kev.

Figure 1 shows the energy loss curves deduced from the different theories for iron, calculations for this substance being readily available. For E/μ below ~50 the theories disagree somewhat, essentially because of the use of different effective ionization potentials. The different theories agree in giving the same constant plateau value.

The ionization and energies of tracks in two Ilford G5 plates were measured by grain counting and multiple Coulomb scattering, respectively, and the results are shown in Fig. 2. Long tracks were selected so that the probable error in grain counting was about two percent. Since the theories give the same plateau value, the sets of observations for the two plates were normalized

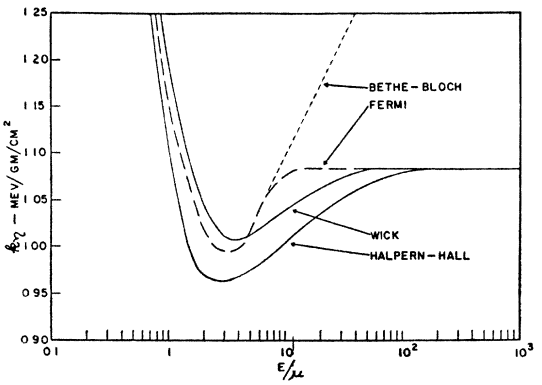

FIG. 1. Theoretical curves for the rate of energy loss in ionizing collisions in iron. Energy transfers less than 10 kev are included. Effective ionization potentials; Bethe-Bloch and Fermi, $I'=26\times13.5$; Wick, $I'=16\times13.5$; Halpern-Hall, $I'=32\times13.5$ ev.

so that the mean grain density for high energy electrons (>20 Mev) in each plate[8] corresponds to the rate of energy loss for AgBr calculated from Fermi's theory for the polarization correction, and the Bethe-Bloch formula, i.e., 1.02 Mev, cm²/g. It is assumed that the production of ions in AgBr crystals only leads to developable grains, and there is no contribution from ionization in the gelatin of the emulsion. The high energy plateau is in agreement with observations by Corson and Keck,[9] who reported the grain density to be constant within two percent for electrons having energies from 10 to 180 Mev; i.e., E/μ from 20 to 360.

To detect a relativistic increase in ionization, it would seem to be necessary that the corresponding energy loss occurs within the AgBr crystal traversed, and is not dispersed in neighboring crystals or gelatin. As is shown by Bohr's treatment,[5] the limiting distance from the path of a particle for ionizing collisions for the plateau will be $\sim c/\nu$; $\nu^2=4\pi ne^2/m$, where n=electron density in the medium, i.e., $\sim10^{-6}$ cm, which is less than the dimensions of the undeveloped AgBr crystal ($\sim3.10^{-5}$ cm).[10] It can also be seen that the plateau sets in at a value of $E/\mu\sim\nu_0/\nu$, where ν_0 is the frequency corresponding to the effective ionization potential, e.g., for iron and AgBr, E/μ (cut-off)$\sim$20 and 30, respectively, in qualitative agreement with the curves in Figs. 1 and 2.

The experimental results seem to indicate the existence of a small increase in ionization beyond minimum up to a limiting plateau. It is hoped to confirm this increase by further observations and it may be possible to compare experimental results with the different theories. If anything, the present results seem to favor that of Wick[11] rather than of Halpern and Hall.[11]

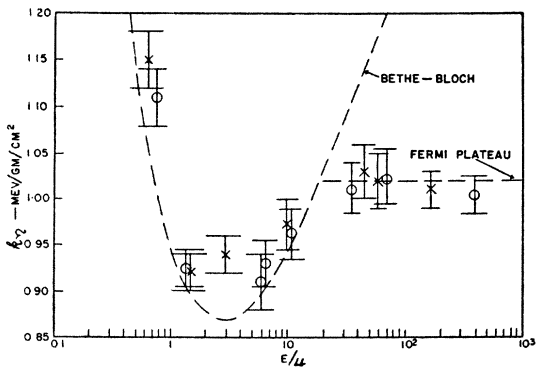

FIG. 2. Dashed curves show Bethe-Bloch energy loss, and Fermi plateau for AgBr. Experimental points, with standard deviations indicated; O—μ-meson decay electrons, and relativistic μ-mesons in sea-level plate. X—high energy electrons, protons, and shower π-mesons in high altitude plate.

We wish to thank Mr. I. B. McDiarmid for assistance with the grain counting and scattering measurements.

[1] W. F. G. Swann, J. Franklin Inst. **226**, 598 (1938).
[2] E. Fermi, Phys. Rev. **57**, 485 (1940).
[3] O. Halpern and H. Hall, Phys. Rev. **73**, 477 (1948).
[4] G. C. Wick, Nuovo Cimento **I**, 302 (1943).
[5] A. Bohr, Kgl. Dansk. Vid. Sels. Math-fys. Medd. **24**, No. 19 (1948).
[6] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941).
[7] L. Voyvodic, Can. J. Research **28**, 315 (1950).
[8] The actual grain densities were 31.7 and 35.7 grains/100μ, with standard deviations of 0.6 grain/100μ.
[9] D. R. Corson and M. R. Keck, Phys. Rev. **79**, 209 (1950).
[10] J. H. Webb, Phys. Rev. **74**, 511 (1948).
[11] Theoretical curves for AgBr have not yet been calculated, and will probably be a few percent different from those for iron.

Neutron Capture γ-Rays from Cd, Cl, and C

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August 7, 1950

SPECIMENS of Cd and of CCl_4 were placed in a beam of thermal neutrons from the graphite pile, *BEPO*. The capture γ-rays were measured by measuring the pulse-height distribution of photo-protons from disintegration of deuterium in an ionization chamber counter[1] placed behind the specimen. A small bismuth block in the center of the neutron beam attenuated the direct pile γ-radiation. The background of pile γ-rays was measured by interposing a neutron absorbing shutter of lithium and boron, which had a transmission of about five percent, equal to that of the CCl_4 sample.

Two similar counters were used. The first was filled with 11 atmos. deuterium gas and was operated at 16 kv, and the second was filled with a mixture of 5 atmos. CH_4 and 6 atmos. of H_2, and was operated at 8 kv. Both counters were made of a 1-mm thick aluminium alloy, which did not capture neutrons appreciably. The sensitive volume was enclosed in a sphere of 4 cm diameter.

The first counter had a trace of nitrogen present, and at first trouble was experienced with a large background from the reaction $N^{14}(n-p)C^{14}$. Later, the proton energy[2] of 630 kev from this reaction was used for calibration and to estimate the resolution. The resolution was ±15 percent of the proton energy, being caused partly by ionization chamber defects, which are observable in the $n-p$ reaction distribution, and partly by the influence of the γ-ray momentum on the pulse-height distribution of the photo-protons. This pure deuterium-filled counter had too low a stopping power to detect γ-rays above about 8 Mev. In order to plot the high energy portion of the spectrum, the second counter filled with the methane-deuterium mixture was used. In this counter, however, electron pulses caused too high a background to detect

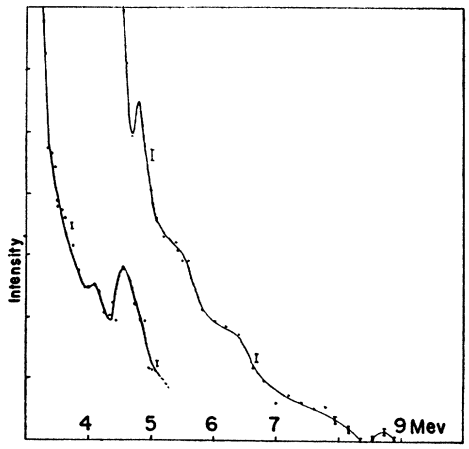

FIG. 1. Neutron capture γ-ray spectrum from cadmium.