Determination of the Residual Current of an Ionization Chamber and the True Conductivity of Dielectric Liquids

ANATOLE ROGOZINSKI
Laboratoire de Physique Cosmique de l'Observatoire de Meudon, France
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A method is described to determine residual current due to phenomena inside of an ionization chamber which are found to be essential for intensity measurements of cosmic rays. In an ionization chamber containing a dielectric liquid, the residual current can be practically identified with the true conductivity of the liquid. It is found that in the case of liquid hexane, the residual current amounts only to one-sixth of the total current. The method to be described here permits one to decide whether or not the true conductivity of the liquid tends to zero, if we continue to purify the liquid, or whether the liquid behaves, with respect to ionizing radiations, as a high pressure gas.

CERTAIN particularities are found for currents in highly isolating dielectric liquids (e.g. saturated hydrocarbons, CS_2, CCl_4, isolating oils, etc.) which cannot be explained by assuming a well-determined conductivity of the studied substances. It has been shown by Jaffé[1] that the current in a liquid (hexane, heptane, etc.) becomes considerably reduced if the liquid is surrounded by a layer of lead. At least one part of the current has, therefore, to be ascribed to the influence of cosmic radiation and of radioactive phenomena. To all of these influences we shall refer as "cosmic radiation."

In order to know the current which is due exclusively to the conductivity of the liquid, we would have to protect our substance completely from cosmic radiation. The same problem arises if we want to determine the residual current which is due to phenomena originating in the interior of an ionization chamber. The main contribution in this case is due to α-particles from natural radioactive contamination in the chamber walls. Steinke, Kolhörster, Pforte, Compton and others[2] have resolved the problem by measuring the current in an ionization chamber in a deep mine, where the cosmic radiation becomes almost entirely absorbed by the matter above the apparatus. The radioactive radiation of the mine was absorbed by a thick lead screen. An analogous study has never been made with an ionization chamber containing a dielectric liquid.

Measurements in a deep mine present certain difficulties which may not be detailed here. We have replaced this method by another one, the principle of which shall be briefly described here.

Let us consider two points, where the intensity of the cosmic radiation I and I' are sensibly different. The currents i_c and i_c' which are produced in a gas-filled ionization chamber placed successively at the two points will be, to a first approximation, proportional to the intensity of the radiation. We should expect, therefore, to obtain a straight line parallel to the pressure axis if we plot the ratio of the two currents at different pressures in a gas chamber.[3] As a matter of fact, this straight line is found only at a pressure above about 10 atmos. This fact shows that there exists, beside the current induced by cosmic radiation, a residual current i_r which is independent of external radiations and has mainly to be ascribed to the action of α-particles from radioactive contamination in the chamber walls. It can be easily seen that the relative influence of the residual current diminishes with increasing pressure, because, while the cosmic-ray current increases with pressure, the current due to α-particles becomes reduced, since the lack of saturation affects, to a much higher degree, the second part of the current. *We are thus led to the conclusion that the ratio of the measured currents $i' : i$ tends, with increasing pressure, to the ratio $\theta = I' : I$ of the intensities of the corresponding cosmic radiation.* This conclusion remains valid even if the observed current is not saturated—as

[1] G. Jaffé, Ann. d. Physik **28**, 326 (1909).
[2] E. S. Steinke, Zeits. f. Physik **48**, 647 (1928); W. Kolhörster, Zeits. f. Geophys. **6**, 341 (1930); W. S. Pforte, Zeits. f. Physik **65**, 92 (1930); A. H. Compton, E. O. Wollan and R. D. Bennett, Rev. Sci. Inst. **5**, 415 (1934).
[3] We admit that each of the components of the radiation loses in the gas a small fraction of its energy.

is always the case in compressed gases, except in the extremely pure rare gases—since it has been shown experimentally that the current is proportional, over a wide range, to the intensity of cosmic radiation. We obtain, therefore, two equations: $i_r+i_c=i$ and $i_r+\theta i_c=i'$, from which $i_c=i[1-(i'/i)]/(1-\theta)$ and $i_r=i[(i'/i)-\theta]/(1-\theta)$. The knowledge of θ permits one to separate the residual and the cosmic components of the total current. It permits one further to measure the absolute intensity of cosmic rays with an ionization chamber containing a gas of about atmospheric pressure, in which we can obtain saturation with a comparatively weak electric field applied to the electrodes of the chamber.

In the case of a dielectric liquid, the residual current has practically to be ascribed to the true conductivity of the liquid only. Indeed, the fraction of this current resulting from natural radioactive contamination of the walls of the chamber would be negligible because of the very small proportion of the ions escaping from the recombination in the ionized columns, produced by the α-particles.

The measurements have been performed (1) in the laboratory (L) and (2) in a room (R) especially protected against natural radioactive radiations. A constant temperature of this room could be maintained for a long time. The room was screened by double walls 1 meter apart, the intervening space was filled with 50 tons of distilled, inactive water, which had a considerable thermal inertia.[4] The measurements in both rooms, (L) and (R), obtained with an ionization chamber filled with pure argon or nitrogen compressed up to 90 atmos.[5] furnished for the barometer effect of the radiation the respective values 2.5 percent and 5 percent per cm Hg. The ratio θ was found to be 0.44.

We have used this value in order to separate the two components, as indicated above, in a hexane chamber,[6] the isolated electrode of which was connected with the (floating) grid of one of the electrometer valves of a bridge device. The stability of the device was sufficient to detect voltage differences of the order of 10^{-4} volt per minute, which corresponds to less than 10^{-16} amp. The measured currents were of the order of 10^{-14} amp.

The temperature at (R) was constant and equal to 14°C, the temperature of (L) varied. A great number of measurements were made to determine the temperature coefficient of hexane. By successive approximations, taking into account the barometric effect of cosmic radiation, we found finally the following values, which are reduced to 760 mm Hg and 14°C: temperature coefficient, 2.2 percent per degree C; total current in (L), 9.0×10^{-4} volt per sec.; total current in (R), 4.8×10^{-4} volt per sec.

In calculating the two components of the current, we found that one-sixth of the total current measured is due to the residual current. Our ionization chamber was not especially designed for conductivity measurements of the investigated liquid and only one approximative value of the absolute conductivity has been obtained. It is of the order of 10^{-19} $\text{ohm}^{-1}\cdot\text{cm}^{-1}$.

We do not want to enter here into discussion of the origin of the conductivity of hexane. It may possibly be caused by some impurities of the substance. The hypothesis that the conductivity of *pure* hexane be zero has been put forward several times,[7] but it has, so far, never been proved unambiguously. As a matter of fact, even at a place where only very little radioactive radiation was present, e.g., in (L), the true conductivity represents only a small fraction of the current, even for a liquid, on which the limit of purification has not been obtained. We want to point out here that only measurements in deep mines, or measurements of the type indicated above, will finally permit us to decide to what extent pure hexane, or other substances with saturated molecules, behave like gases at high pressure.

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[4] A. Dauvillier, Bull. Astronomique **10**, 123 (1937).
[5] A. Dauvillier and A. Rogozinski, J. de phys. et rad. (7) **9**, 152 S (1938).
[6] A. Rogozinski, J. de phys. et rad. (7) **8**, 128 S (1937).
[7] G. Jaffé, reference 1; J. Adamczewski, Nature **137** 994 (1936).