TABLE I. Relative weights of B^{10} states.

E_x	Neutron weight	Gamma-ray weight A	Gamma-ray weight B
3.68 Mev	26	21	21
2.22	24	31	23
1.78	7	17	25
0.76	43	31	31
Total, excited states	100	100	100
0.00 (ground state)	38	—	—

scheme suggested by Ajzenberg.[3] In "A" the 410-kev gamma is assigned to a transition between the 2.22- and the 1.78-Mev states; in "B" the 410-kev gamma is omitted from the scheme. The agreement is somewhat better under assumption "A."

† Assisted by a contract with the AEC.

[1] Johnson, Laubenstein, and Richards, Phys. Rev. **77**, 413 (1950).
[2] Lattes, Fowler, and Cuer, Proc. Phys. Soc. (London) **A59**, 883 (1947); N. Nereson and F. Reines, Rev. Sci. Instr. **21**, 534 (1950).
[3] F. Ajzenberg, Phys. Rev. **82**, 43 (1951).
[4] Rasmussen, Hornyak, and Lauritsen, Phys. Rev. **76**, 581 (1949); V. K. Rasmussen (private communication).
[5] S. T. Butler, Proc. Roy. Soc. (London) **A208**, 559 (1951).
[6] I. Resnick and S. S. Hanna, Phys. Rev. **82**, 463 (1951); F. L. Canavan (to be published).
[7] L. Diesendruck (private communication).
[8] F. A. El-Bedewi, Proc. Phys. Soc. (London) **A65**, 64 (1952); F. Ajzenberg, Phys. Rev. **87**, 205 (1952); C. F. Black, Phys. Rev. **87**, 205 (1952).

Thermoluminescence and Changes of Color Centers in LiF

J. SHARMA
Khaira Laboratory of Physics, University College of Science, Calcutta, India
(Received June 17, 1952)

PRINGSHEIM and Yuster[1] have reported that on warming LiF, x-rayed at low temperature the emission of a blue glow peak and disappearance of an absorption band, 3400A both take place at −135°C. They have observed that the x-rayed sample left at room temperature shows a blue color due to an absorption band at 6200A. In the course of time, this band gives place to an absorption band at 4450A. In the present work their observations with a single crystal have been confirmed by using powdered LiF colored with 10-kv cathode-rays at liquid oxygen temperature. The sample was prepared by double decomposition of LiCl (Merck) and NH_4F in the laboratory.

By employing a high[2] rate of heating, some new glow peaks have been recorded [continuous curve (a)]; it is seen that the peak at −135°C is not single but consists of two peaks at −142°C and −130°C. If heating is not stopped at room temperature, a broad glow peak is given out at about 400°C, which to the naked eye appears to be richer in light of longer wavelengths (yellow-red). The blue color of the sample changes now to yellowish-brown, obviously due to a shift of the absorption band. The sample then becomes red luminescent under blue light irradiation. Klick[3] has assumed this to be due to absorption at the M-band, but Pringsheim[4] has assigned the red luminescence to the new band that develops from the 6200A band. The broken curve (b) of Fig. 1 shows the change in absorption centers taking place at about 400°C. To get it, LiF bombarded at room temperature was irradiated with faint blue light (tungsten lamp across glass filter transmitting shorter wavelengths than 5100A), and the scattered light was received by a photomultiplier tube. The sample was heated as in the thermoluminescence experiment. The curve gives a measure of the scattered blue light at different temperatures. As heating is increased, the sample begins to give a faint glow peak at 400°C or so, and the amount of scattered blue light is now diminished. This shows increased absorption of blue light due to a shift of the original absorption band.

The curve (c) shows similarly the appearance of red fluorescence at 400°C. A sample bombarded at liquid oxygen temperature was irradiated with blue light, and a photomultiplier (1P22) tube with red filter (transmitting between 6070A and the red end) in front

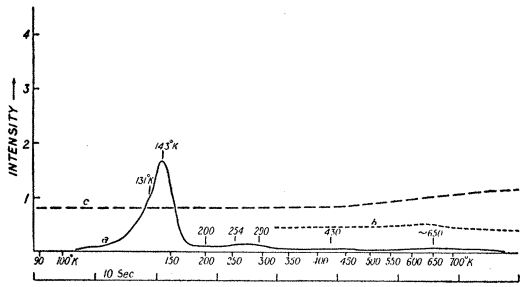

FIG. 1. The continuous curve (a) gives the thermoluminescence record of LiF excited with cathode rays at liquid oxygen temperature. The curve (b) gives a measure of the blue light scattered by LiF during heating of a sample colored at room temperature. The rise at 650°K in this curve indicates the last thermopeak, and thereafter the slight fall of the smooth curve indicates creation of an absorption band in the blue region. The curve (c) gives a measure of red light received from the sample when it was irradiated with blue light. The rise in the curve at 650°K shows that the sample at this temperature becomes red luminescent under blue light. The curve (c) was recorded simultaneously with the curve (a) in the same run of thermoluminescence experiment.

of its cathode received scattered light from the sample, passing through the filter. The sample was heated, and a record of the red light from the sample was made. The rise in the curve shows that at this temperature the sample has become red luminescent under blue light excitation.

If the coloration of the sample is done at low temperature, this change to red luminescence takes place at 400°C, but if the coloration is done at room or higher temperature the transition temperature becomes still higher.

During bombardment at low temperature the sample fluoresces blue under cathode-rays, but intense bombardment makes the sample red luminescent in a short time. Thus the red luminescence, which is excitable in the bombarded sample by blue light can also be developed to some extent, by intense bombardment at low temperature. Apparently this luminescent center is formed by an aggregate of primary centers.

The author is thankful to Prof. S. N. Bose, Khaira Professor of Physics, Calcutta University, for his guidance and constant interest in the work.

[1] P. Pringsheim and P. Yuster, Phys. Rev. **78**, 293 (1950).
[2] J. Sharma, Phys. Rev. **85**, 692 (1952).
[3] C. C. Klick, Phys. Rev. **79**, 894 (1950).
[4] See footnote 5 of reference 3.

A Theory of Contact Noise

RICHARD L. PETRITZ
U. S. Naval Ordnance Laboratory, White Oak, Maryland and Catholic University of America, Washington, D. C.
(Received June 6, 1952)

CURRENT flow across a contact difference of potential such as exists in rectifiers and transistors is of the form:

$$i=R(T, E, U)\exp(-E/kT)[1-\exp(-eU/kT)], \qquad (1)$$

where E is the height of the energy barrier that exists because of the equalization of the Fermi levels of the two "materials" making up the contact (the "materials" may be of the same bulk nature as in a $P-N$ junction in germanium), U is the applied potential, and R is a slowly varying function of T, E and U.

The physical basis for the exponential dependence of the current on E is that the current is determined primarily by the number of electrons in the "neighborhood" of the contact with thermal energy greater than E. This number is independent on the temperature of the lattice and electrons in the "neighborhood" of the contact. We will not in this note attempt to define the size of the "neighborhood" whose temperature determines the current flow except to say that it is certainly larger than the mean free path for electron-lattice scattering.

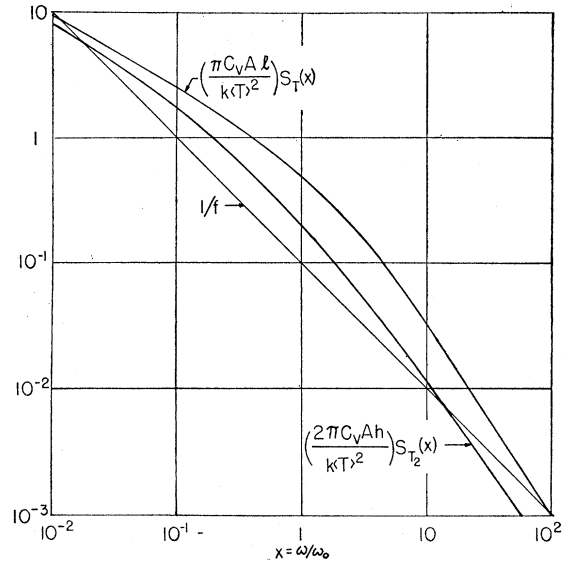

FIG. 1. Power spectra of temperature fluctuations.

The theory of contact noise that we are proposing is based on the idea that temperature fluctuations in the "neighborhood" of the contact are the source of the contact noise.

In order to illustrate this idea we consider a $P-N$ junction in, say, germanium and assume that the "neighborhood" whose temperature controls the current extends a distance l each side of the center of the junction. Later we use a weighting factor to decrease the influence of regions further away from the junction in a continuous manner. The assumption of a finite uniform "neighborhood" is considerably simpler to treat mathematically and illustrates the features of the theory.

Considering a fluctuation ΔT in the temperature of the "neighborhood," the current is:

$$i=B(\langle T\rangle)\exp\{-E/[k\langle T\rangle(1+\Delta T/\langle T\rangle)]\}; \tag{2}$$

[we neglect in this note temperature fluctuation effects in $B(\langle T\rangle)=R[1-\exp(-eV/k\langle T\rangle)]$—they can be shown to be small compared to the effects in $\exp(-E/kT)$].

Expanding the exponential we have:

$$\Delta i=i-\langle i\rangle=\langle i\rangle E\Delta T/(k\langle T\rangle^2). \tag{3}$$

We can write down the total fluctuations in the current, using the general result that the temperature fluctuations of a body of thermal capacity C in contact with a heat reservoir are given by the expression:[1]

$$\langle\Delta T^2\rangle=k\langle T\rangle^2/C. \tag{4}$$

For our problem $C=C_VAl$, where C_V is the specific heat of the material, and A is the cross-sectional area of the junction. Then:

$$\langle\Delta i^2\rangle=\langle i\rangle^2E^2/(k\langle T\rangle^2C_VAl). \tag{5}$$

This result is in qualitative agreement with certain characteristics of contact noise: (1) The noise power is proportional to the square of the average current, (2) the noise is not strongly temperature dependent, (3) point contact rectifiers and transistors are noiser than broad area devices.

To investigate the power spectrum of the noise we first find the correlation function of the current and then the power spectrum:

$$\langle\Delta i(0)\Delta i(t)\rangle=[\langle i\rangle^2E^2/(k^2\langle T\rangle^4)]\langle\Delta T(0)\Delta T(t)\rangle,$$
$$G_i(f)=[\langle i\rangle^2E^2/(k^2\langle T\rangle^4)]S_T(f),$$
$$S_T(f)=4\int_0^\infty(\cos 2\pi ft)\langle\Delta T(0)\Delta T(t)\rangle dt. \tag{6}$$

The power spectrum of T is that of a diffusion mechanism since heat flow is basically a diffusion process. A one-dimensional heat flow seems appropriate since heat flow to and from the "neighborhood" will occur primarily within the sample.

The power spectrum of the one-dimensional diffusion mechanism has been obtained by McFarlane[2] and Miller[3] in regard to a theory of contact noise based on density fluctuations of ions near the contact. The corresponding expression for the power spectrum of the temperature fluctuations is:

$$S_T(x)=\frac{k\langle T\rangle^2}{C_VAlx^{\frac{1}{2}}}\{1-\exp(-x^{\frac{1}{2}})[\cos x^{\frac{1}{2}}+\sin x^{\frac{1}{2}}]\}, \tag{7}$$

where $x=\omega/\omega_0$, $\omega_0=2D/l^2$, $D=K/C_V$, and K is the coefficient of heat flow. The spectrum is plotted in Fig. 1.

An important characteristic of this theory is that the turnover frequency ω_0 is not strongly temperature dependent. The parameter l is involved in ω_0 and also in the magnitude of the noise [Eq. (7)] making an internal check of the theory possible.

Weighing the effect of a local temperature fluctuation $\Delta T(y)$ at a distance y from the center of the junction by an exponential factor $\exp(-y/h)$ the power spectrum is:

$$ST_2(x)=\left[\frac{k\langle T\rangle^2}{C_VAh2\pi}\right]\frac{1}{x^{\frac{1}{2}}[1+2x+2x^{\frac{1}{2}}]}, \tag{8}$$

where $x=\omega/\omega_0$, $\omega_0=2D/h^2$, and we have used mathematical results of Miller.[3] $ST_2(x)$ and the characteristic $1/f$ spectrum of contact noise are plotted on Fig. 1 and examination shows that ST_2 approximates a $1/f$ law within ± 3 db over nearly five decades.

A more detailed account of this theory is under preparation for publication.

Helpful discussions with Prof. Uhlenbeck and with Dr. W. W. Scanlon are gratefully acknowledged.

[1] R. H. Fowler, *Statistical Mechanics* (Cambridge University Press, London, 1936).
[2] G. G. McFarlane, Proc. Phys. Soc. (London) **B63**, 807 (1950).
[3] William Miller (unpublished).

The Mass of a Photon

L. S. KOTHARI
Cavendish Laboratory, Cambridge, England
(Received May 19, 1952)

THE method, developed by Riesz, of solving the hyperbolic equation by the analytical continuation of an integral which is an analytic function of an arbitrary parameter α has been applied to different problems in electrodynamics by various authors.[1-4] Fremberg[1] uses a definition for the Riesz potential which is a generalization of the Maxwell potential in the α-plane. The equivalence of this definition and the λ-limiting process has been established by Ma.[5] Auluck and Kothari[4] use a modified definition for the Riesz potential and have shown that it is a generalization of the Wentzel potential in the α-plane. The purpose of the present note is to show that in any problem the use of the modified definition of Auluck and Kothari is equivalent to assuming a finite rest mass for the photon and finally letting it tend to zero. This method of assuming a finite rest mass for the photon has been widely used in present day electrodynamics to avoid certain infrared divergences. There the rest mass is introduced arbitrarily. This unphysical assumption can, it seems, be justified by the fact that one would get the same results using consistently the analytical continuation method. However, in any problem it is simpler to introduce the mass directly.

We define the metric tensor $g_{\mu\nu}$ as $g_{00}=1$, $g_{11}=g_{22}=g_{33}=-1$; $g_{\mu\nu}=0(\mu\neq\nu)$. The velocity of light is taken as unity. The scalar product of two four-vectors A_μ and B_μ is denoted by $[AB]$. The (positive) length of the space part of A_μ is written as $|A|$.

The Riesz potential at any point x due to a point electron moving with a velocity ϑ_μ is defined as [Eqs. (5) and (11) of I]

$$A_\mu{}^\alpha(\kappa)=H(\alpha)e/2\pi^2\int_D\int_{-\infty}^{z}k^{\alpha-2}\sin[k,x-z']\vartheta_\mu' d^4k d\tau', \tag{1}$$