during its falling is impossible; the central body of the Schwarzschild solution cannot be formed by immovable matter. For the matter of the central body of the Schwarzschild solution the condition (6) is fulfilled only if the collapse is oscillatory. The classical Schwarzschild solution is true only outside the pulsating matter.

From the location of light cones it follows that during the oscillatory collapse all particles fly through the centre simultaneously. The integral (5) is true in this case for every τ. If particles fly through the centre unsimultaneously the integral (5) becomes untrue at the moment of the intersections of the world lines of the particles.

This circumstance was not taken into account in [3]. The oscillatory nature of the collapse is the natural consequence of the convertability of the equations of motion.

A detailed article will be published in Zh. Eksp. Teor. Fiz.

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SINGLE-BEAM MEASUREMENT OF BOSE-EINSTEIN FLUCTUATIONS IN A NATURAL GAUSSIAN RADIATION FIELD

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Excess noise caused by Bose-Einstein fluctuations in the radiation from the anode of a carbon-arc was detected in the photo current of a cooled InSb photodiode. Its dependence on several parameters was found to agree with our theory.

Bose-Einstein statistics predicts an excess noise effect in the number, n, of photons present in N modi of the radiation field [1]. The ratio, δ, of excess noise power to pure shot noise power is given by $\delta = \langle n \rangle / N$ and is called the "degeneracy factor".

For a radiation field in equilibrium at temperature T, we have $\delta = (\exp[1.438/\lambda T]-1)^{-1}$, so that δ becomes significant only if λT is at least of the order of 1 cm$^{\text{o}}$K. The underlying thermodynamical arguments do not strictly apply to the non-equilibrium case when an external beam is extracted from the radiation field and detected by a (cooled) photocell. In the calculation of the excess noise factor δ_D in the photo-emission current, i, we may, however, proceed by associating the field intensity fluctuations with fluctuations in the probability of photo emission. In our previous paper [2] it has been shown that

$$\delta_D = F(\lambda_0^2/\Theta A)\ (\langle i \rangle / eB) \qquad (1)$$

in the case that the spectral radiation intensity is constant within a relatively small frequency-band B around central wavelength λ_0 and is zero outside this band. When the dependence of spectral intensity on wavelength has a triangular shape within a frequency-band B, δ_D in eq. (1) should be multiplied by 1.33.

A is the detector area, Θ is the solid angle subtended by the incident beam and $-e$ is the electron charge. Eq. (1) holds if Θ exceeds largely the angle of spatial coherence, λ_0^2/A and if $B \gg f_n$, where f_n is the frequency at which the noise analyzer is tuned. Under the latter condition we have that δ_D is independent of f_n. The factor F equals unity, if the radiation is completely polarized and $F = \frac{1}{2}$ if it is unpolarized. It should be noted that eq. (1) does not include explicitly the characteristic parameters of the light *source* (such as temperature or emissivity). In this investigation the validity of eq. (1) was shown by direct measurements of the noise power in a single-beam experiment with one photo-emissive cell. The Gaussian character of the light

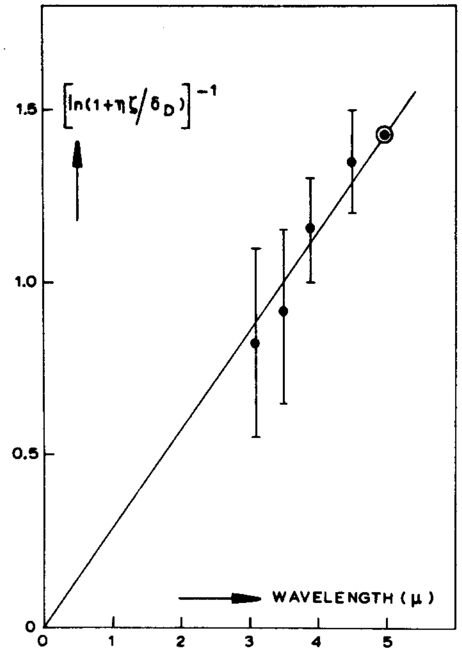

Fig. 1. Experimental check of dependence of excess noise factor δ_D on wavelength for a radiation source with T_r = 3800°K.

beam was ensured by using a *natural* (thermal) light source based on many uncorrelated spontaneous emissions. Our attempts to utilize the solar radiation filtered at λ_0 = 1.8μ and detected by a Ge-photo diode failed because of unfavourable meteorological conditions. The anode (T = 3800°K) of a carbon-arc in combination with a cooled InSb-photo-diode Texas Instruments, type ISV 1101 ($A = 7.8 \times 10^{-3}$ cm^2), which has a good quantum efficiency up to 5.4μ and a sufficiently low time constant, appeared to be more successful. By means of a concave mirror an image of the anode was formed on the entrance slit of a Carl Leiss single monochromator with mirrors and a rock salt prism. The spectral bandwidths selected were of the order of 0.5μ in the range 0.9 - 5.0μ. The detector was mounted at 0.9 cm behind the exit slit and was cooled at liquid-N_2 temperature. Its dark current at zero bias voltage was about 16μA. A feed-back circuit with a response time of 1 msec ensured that the bias voltage over the diode did not exceed 10mV so as to obtain optimum performance [3]. The reciprocal value of this response time is sufficiently lower than the frequency f_n = 83 kc/s at which the noise power was measured. The heterodyne noise analyser used, which had an effective noise bandwidth of 1 kc/s, has been described in ref. 4. The noise measured was calibrated by a standard noise diode in parallel with the photodiode. No polarizer was inserted in the light-beam. It is easily seen that the conditions underlying eq. (1), viz. $\Theta A/\lambda_0^2 \gg 1$ and $B \gg f_n$, are fulfilled in our measurements.

Table 1

$\langle i \rangle$	Θ/Θ_0	ζ/ζ_0	δ_D(exp)	δ_D(th)
50 μA	≡1	≡1	19.5%	19.5%*
42	1	0.84	16.5	16.5
42	0.84	1	20.0	19.5
30	1	0.60	13.5	11.7
31	0.74	0.84	16.0	16.5
30	0.60	1	20.0	19.5

* adapted

Dark current and amplifier noise was subtracted. Under conditions where no Bose-Einstein excess noise should occur, some spurious excess noise above shot noise level was still observed. Its power increased almost proportionally to $\langle i \rangle$ and was, virtually, independent of λ_0 if $\langle i \rangle$ was held constant, so that it could easily be corrected for. This spurious effect was due to random deviations from zero cell potential [3].

As the absolute spectral emission intensity of the anode happens to be reasonably well described by an effective radiation temperature T_r = 3800°K in the investigated spectral range, it follows from

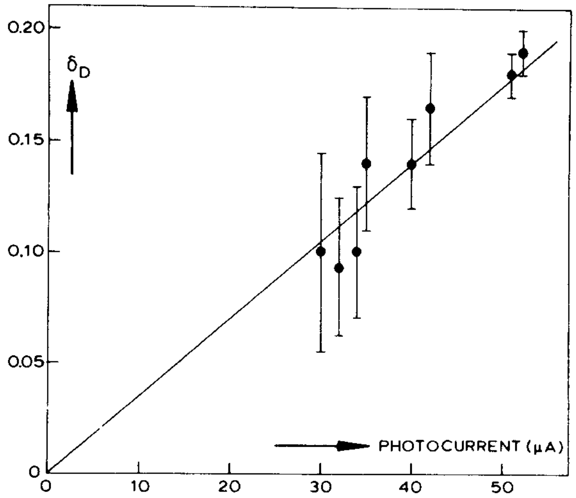

Fig. 2. Linear dependence of excess noise factor δ_D on photocurrent $\langle i \rangle$ at λ_0 = 4.5μ.

eq. (1) that by applying Planck's law [2]

$$\delta_D = \eta\zeta/(\exp[1.438/\lambda_0 T_r]^{-1} \quad . \qquad (2)$$

Here η is the quantum-efficiency of the detector, while ζ allows for radiation losses between light source and detector. A plot of $[\ln(1+\eta\zeta/\delta_D)]^{-1}$ versus λ_0 should yield a straight line, since $\eta\zeta$ does not vary significantly with λ_0. This expectation is confirmed experimentally in fig. 1 where $\eta\zeta$ is adapted, such that eq. (2) is obeyed at $\lambda_0 = 5.0\mu$. The value of $\eta\zeta = 0.22$ required is consistent with what is known about η and the expected reflection and absorption losses in the optical system and detector window.

The accuracy of the measurements plotted in fig. 1 is such that the variation of the spectral intensity of the light source within the spectral band transmitted needs not to be allowed for.

The proportionality between δ_D and $\langle i \rangle$, predicted by eq. (1) at constant values of λ_0, Θ, A and B, could be checked by varying $\langle i \rangle$ with the aid of optical attenuation filters at $\lambda_0 = 4.5\mu$ (see fig. 2). Within their error limits the experimental points make reasonably well a straight line through origin, the slope of which agrees within an error of about 20% with the value calculated when known values are inserted for λ_0, Θ, A and B in eq. (1).

Finally, table 1 compares experimental and theoretical δ_D-values predicted by eq. (1) while $\langle i \rangle$ was varied at $\lambda_0 = 4.5\mu$ by additional optical attenuation (ζ/ζ_0) and/or by reduction of solid angle (Θ/Θ_0). The constants in eq. (1) are adapted such that the theoretical and experimental δ_D values coincide at $\langle i \rangle = 50\mu$A, where by definition $\zeta = \zeta_0$ and $\Theta = \Theta_0$.

It is seen from table 1 that combinations of Θ/Θ_0 and ζ/ζ_0 resulting into a *same* value of $\langle i \rangle$ yield *different* values of δ_D in accordance with theory.

Independently Gubler and Strutt [5] have measured excess noise in radiation from a high-current high-pressure Ar-discharge. By varying the discharge pressure and holding the other parameters (such as λ_0, B, Θ) constant they have found excess noise factors ranging from 1 - 1.15 in the InSb diode current at $\lambda_0 = 4.85\mu$, which were in agreement with their theory based on Bose-Einstein photon fluctuations and partition noise. In contrast to our theory [2], which was based on a simple stochastic association of photo-emission probability and radiation intensity at the place of the *detector*, their theory involves a rather elaborate and detailed analysis of the composition and the emission and absorption characteristics of the inhomogeneous light *source*. Our experiments performed under varying conditions of λ_0, Θ and optical attenuation meant to show that a specification of the radiation field at the place of the detector suffices to predict theoretically the excess noise factor in the photo current (see eq. (1)). Only the Gaussian character, but no details of the lifht-source enter into our analysis.

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