Letters to the Editor

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A Suggestion Regarding the Spectral Density of Flicker Noise

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AN explanation of the flicker noise in oxide cathodes was first given by Schottky.[1] He assumed that the work function is influenced by the presence on the outer surface of impurity atoms, the density of which was subject to fluctuation because of diffusion effects. The expression for the mean square noise current per unit frequency interval based on this assumption is

$$\langle i^2\rangle_{\mathrm{Av}}\sim\tau I^2/(1+\tau^2\omega^2), \tag{1}$$

where I is the average current and τ is the average time spent by an atom on the surface. Assuming $\tau\omega\gg1$ we find

$$\langle i^2\rangle_{\mathrm{Av}}\sim I^2/\tau\omega^2. \tag{2}$$

The experimental results, however, follow more closely the law $\langle i^2\rangle_{\mathrm{Av}}\sim I^2/\omega^{1.25}$. Similar discrepancies[2] are found in other cases where the same assumptions might be used to explain a fluctuating barrier height e.g., metal semiconductor rectifiers, lead sulfide cells and carbon microphones. The frequency dependence may be close to ω^{-1}. Also the dependence on the current may differ somewhat from the square law, but this may be due to slight deformations caused by changing the applied electric field, as was suggested by Christensen and Pearson.[3]

Recently, MacFarlane[4] has extended and modified Schottky's theory in order to obtain the correct frequency dependence. His result is

$$\langle i^2\rangle_{\mathrm{Av}}\sim I^{2m+2}/\omega^{2m+1}, \quad \text{with} \quad 0<m<\tfrac{1}{2}. \tag{3}$$

Although this improves the agreement with experiment considerably, neither theory explains the relative insensitivity of the flicker noise to the temperature. This is so because in Schottky's expression (2) the relaxation time for the diffusion will depend on the temperature according to

$$\tau=\tau_0\exp(Q/kT),$$

and because in (3) the proportionality factor depends strongly on T.

More recently Richardson[5] has obtained a $1/\omega$ dependence without a strong temperature influence by considering the contact between two rough surfaces and making rather special assumptions about the statistical properties of the surface irregularities.

It is our aim to show that a slight modification of Schottky's theory will describe both the frequency and the temperature dependence correctly. Our fundamental hypothesis is that there will be a certain spread in the values of the diffusion activation energy, Q, at different points of the barrier surface. More precisely we suppose that the fraction of the barrier surface having a value of Q between Q and $Q+dQ$ is given by $f(Q)dQ$. This leads immediately instead of (1) to

$$\langle i^2\rangle_{\mathrm{Av}}\sim\int_0^\infty dQf(Q)\tau I^2/(1+\tau^2\omega^2)=(I^2/\omega)\int_0^\infty dQf(Q)\tau\omega/(1+\tau^2\omega^2).$$

The expression $\tau\omega/(1+\tau^2\omega^2)$ as a function of Q, will show a sharp maximum at $Q_m=-kT\ln(\tau_0\omega)$, corresponding to the value τ_m of τ determined by $\tau_m\omega=1$. Assuming that $f(Q)$ varies relatively little in a range of the order of kT, we can also write

$$\langle i^2\rangle_{\mathrm{Av}}\sim(I^2/\omega)f(Q_m)\int_0^\infty dQ\tau\omega/(1+\tau^2\omega^2).$$

The integral can be evaluated by taking as a new variable $z=\tau/\tau_m$ and using $\tau_m\omega=1$. This leads to

$$\int_0^\infty dQ\tau\omega/(1+\tau^2\omega^2)=kT\int_\delta^\infty dz/(1+z^2), \quad \text{where} \quad \delta=\exp(-Q_m/kT).$$

As we must expect that $Q_m\gg kT$ we can integrate from zero to infinity and obtain $kT\pi/2$. Therefore

$$\langle i^2\rangle_{\mathrm{Av}}\sim(I^2/\omega)Tf[-kT\ln(\tau_0\omega)]. \tag{4}$$

We will obtain the often observed proportionality with ω^{-1} when $f(Q)$ in a certain range does not depend on Q. We wish to emphasize that in order to have the ω^{-1} law from $\omega=10^7$ to $\omega=1$ sec.$^{-1}$ we only need a "homogeneous" spread in Q of about 0.25 ev. For according to (4) the extreme values of Q that we have to consider are $-kT\ln(10^7\tau_0)$ and $-kT\ln(\tau_0)$. Their difference is $kT\ln(10^7)=0.25$ ev. It is known that such a variation in Q may occur under the influence of inhomogeneous strains.

Using results reported by Miller,[6] we find it possible to describe the noise spectrum of a silicon rectifier at room temperature and at liquid air temperature, in the range $\omega=10^6$ to $\omega=10^2$ sec.$^{-1}$, by having $f(Q)$ vary gradually in a range of Q values about equal to the one mentioned.

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Nuclear Magnetic Moments of the Gallium Isotopes

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IN a recent letter with the above title, Béné, Denis, and Extermann[1] discuss an interpretation of the observed discrepancy between the moments of the isotopes of gallium as determined from magnetic resonance experiments and from observations on the Zeeman effect of the hyperfine structure of gallium in the $^2P_{\frac{1}{2}}$ state. The latter of these observations yields both the h.f.s. splitting at zero field ($\Delta\nu$) and the ratio of the nuclear g_I to the electronic g_J. Béné *et al.* apply corrections arising from the finite nuclear size to the value of the magnetic moment as calculated from $\Delta\nu$. Unfortunately, the calculation of a magnetic moment from $\Delta\nu$ is subject to rather considerable uncertainties and a discrepancy of 0.65 percent between the directly measured moment and the calculated one cannot be considered as evidence of the existence of an effect arising from finite nuclear size. However, the g values, obtained from h.f.s. measurements, given by Becker and Kusch[2] are obtained directly from the observed ratio g_I/g_J, and the correction given by Béné *et al.* is entirely meaningless when applied to these experimental quantities.

The nuclear resonance experiments and the h.f.s. experiments determine, in each case, the quantity $g_I\mu_0H'/h$ where H' is the external applied magnetic field, H_0, modified by diamagnetic, or possibly paramagnetic, effects of the electron configuration. A different g_I can be obtained in the two methods, only if H'/H_0 is different in the molecule studied in the nuclear resonance experiments ($GaCl_3$) and in the atoms used in h.f.s measurements. In the nuclear resonance method, large shifts have been observed[3] in the resonance frequency of a nucleus in a metal and in a salt. These effects have been discussed[4] in terms of a paramagnetic field at the nucleus due to conduction electrons in a metal.

It may be worth while to indicate the present status of the measurements of the moments of the gallium isotopes. From the results of Pound[5] and of Bitter[6]

$$\mu(\mathrm{Ga}^{71})/\mu(H^1)=0.9148\pm0.0004$$

and

$$\mu(\mathrm{Ga}^{69})/\mu(H^1)=0.7203\pm0.0006,$$

where the moments are uncorrected for diamagnetic effects.

Becker and Kusch have calculated the moments of the gallium isotopes on the basis of the assumption that $g_J(^2P_{\frac{1}{2}})=\frac{2}{3}$. Since this assumption is subject to correction because of the anomalous spin moment of the electron, and since an arithmetical error exists in the previously published values, the data have been recalculated. With the help of the known auxiliary ratios $g_J(^2P_{\frac{1}{2}}, \mathrm{Ga})/g_J(^2S_{\frac{1}{2}}, \mathrm{Na})$ and $g_I(H^1)/g_J(^2S_{\frac{1}{2}}, \mathrm{Na})$:

$$\mu(\mathrm{Ga}^{71})/\mu(H^1)=0.9078\pm0.0015$$

and

$$\mu(\mathrm{Ga}^{69})/\mu(H^1)=0.7146\pm0.0015.$$

In each case the discrepancy between the nuclear resonance values and the h.f.s. values is about three times the sum of the stated uncertainties. The discrepancy appears to be real, especially in view of the excellent agreement between the ratio of the moments of the two isotopes of gallium.

In the experiments on the determination of the magnetic moment of the electron,[7] a large volume of data on the frequencies of lines in the h.f.s. spectrum of Ga was obtained. Nine sets of data exist from which it is possible to determine the ratio g_I/g_J for Ga^{69}. It is then found that $\mu(\mathrm{Ga}^{69})/\mu(H^1)=0.7143\pm0.0015$. The agreement with the ratio previously obtained from h.f.s. data is excellent and points to the reality of the discrepancy of about 0.7 percent between the ratio obtained from the nuclear resonance method and h.f.s.

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Cosmic Radiation and Radio Stars

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THE normal radio wave emission from the sun amounts to 10^{-17} of the heat radiation, and increases during bursts[1] to as much as 10^{-13}. If a radio star, e.g., the source in Cygnus, is situated at a distance of 100 light years, its radio emission is of the order of 10^{-4} of the heat radiation of our sun. It is very unlikely that the atmosphere of any star could be so different from the sun's atmosphere as to allow a radio emission which is 10^9 to 10^{13} times greater, and it seems therefore to be excluded that the source could be as small as a star. The recent discovery[2] that the intensity variations of radio stars is a "twinkling" makes it possible to assume larger dimensions.

Ryle has suggested that there should be a connection between radio stars and cosmic radiation.[3]

According to a recent development of Teller and Richtmyer's theory of cosmic radiation, the sun should be surrounded by a "trapping field" of the order 10^{-6} to 10^{-5} gauss, which confines the cosmic rays to a region with dimensions of about 10^{17} cm (0.1 light year).[4] It is likely that almost every star has a cosmic radiation of its own, trapped in a region of similar size. We suggest that the radio star emission is produced by cosmic-ray electrons in the trapping field of a star.

Electrons with an energy $W\gg m_0c^2$ moving in a magnetic field H radiate at a rate

$$-dW/dt=(2e^2/3c)\omega_0^2\alpha^2, \tag{1}$$

where[5] $\omega_0=eH/m_0c$ is the gyro-frequency corresponding to the rest mass m_0, and $\alpha=W/m_0c^2$. Most of the energy is emitted with a frequency of the order

$$\nu=\omega_0\alpha^2/2\pi=2.8\times10^6H\alpha^2\ \mathrm{sec.}^{-1}. \tag{2}$$

As soon as the energy is much higher than the rest energy the emitted frequency becomes much higher than the gyro-frequency, a phenomenon which is observed in large synchrotrons, where the electron beam emits visual light.[6]

According to (2) an emission of radio waves of 100 Mc/sec. requires

$$H\alpha^2=36\ \mathrm{gauss}. \tag{3}$$

The acceleration process of cosmic radiation should accelerate electrons as well as positive particles. In the solar environment the electron component is eliminated by Compton collisions with solar light quanta as discussed by Feenberg and Primakoff.[7] In the neighborhood of a star which does not emit much light, the electrons would be accelerated until their energy is so high that they radiate. The wave-length falls in the meter band if, for example, $\alpha=300$ ($W=1.5\times10^8$ ev) and $H=3\times10^{-4}$ gauss. This field is about 100 times the estimated strength of the sun's trapping field. As the strength is determined by the "interstellar wind," a radio star should be situated in an interstellar cloud moving rather rapidly relative to the star.

In order to account for the total energy emitted by a radio star we must suppose either that the radio emission is a transitory phenomenon, lasting a time which is short compared to the lifetime of cosmic rays in the trapping field (10^8 years), or that the cosmic-ray acceleration close to the star is supplemented by a Fermi process[8] further out in the trapping field.

According to the views presented here, a radio star must not emit very much light, and should be situated in an interstellar cloud. This would explain why it is so difficult to find astronomical objects associable with the radio stars.

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The Doublets of N^{15} and O^{16}

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THE nuclear energy-level spectra[1,2] of N^{15} and O^{16} are each characterized by two or more doublets having splittings of 30 to 200 kev and separated by about 1 Mev or more, in the region of excitation 5 to 8 Mev. The lack of structure[1] in the ground state of N^{15} and the importance of spin-orbit coupling in the heavier nuclei[3] suggest that the spin-orbit coupling energy is probably too large for these to be spin-orbit doublets. It is noteworthy that these nuclei at the end of the p-shell in the usual shell model[4] have a much wider gap from the ground level to the first known excited state than have other light nuclei, and the first excitation energy, 5 or 6 Mev, seems to be the energy required to excite a nucleon from the p-shell to the next shell. The nuclear spin and magnetic moment of F^{19}, being similar to a proton's, indicate that the next nucleon state is an s-state. In O^{16}, such an excited s-nucleon, if loosely coupled to the remaining $^2P_{\frac{1}{2}}$ hole of the p-shell (similar to N^{15} or O^{15}) would give rise to adjacent states having $I=0$ and 1, a sort of doublet which might be called an "intershell j-j coupling doublet" or simply a "j-j doublet." Calculations neglecting tensor forces show that for most types of central attractive forces between nucleons the