a constant. Equation (1a) is Einstein's "cosmological" equation and its solution is well known.

Applying (1b) to the spherically symmetric problem we made a special choice[1] of Λ_β^α which led us to the following solution:

$$ds^2=\gamma dt^2-\gamma^{-1}dr^2-r^2\sin^2\theta d\phi^2-r^2d\theta^2, \quad (2)$$

where $\gamma=1-(2m/r)\exp(l/r)$ and l is introduced as a universal length, arbitrarily chosen equal to the electronic Compton wavelength; $\exp(l/r)$ is $1+10^{-10}$ for $r=1$ cm and is much closer to unity at larger distances. So that (2) is essentially equivalent to Schwarzschild's line element, and all results of general relativity remain unchanged. However, the corresponding gravitational potential $V=-(m/r)\exp(l/r)$, equivalent to Newton's for all macroscopic considerations, is remarkably large in the small. In the nuclear range, for two nucleons such gravitational interaction is of the order of 2 Mev (magnitude of the binding energy of the deuteron).

We have mentioned the calculation above only to illustrate the potentiality of general relativistic methods in dealing with the very small. Other alternatives are being investigated and will be presented when the calculations are completely carried through.

[1] Namely, Λ_β^α diagonal, the four elements being chosen so that

$$\Lambda_2^2=\Lambda_3^3,\quad \Lambda_2^2=\frac{l}{r^3}(g_{44}-1),\quad \Lambda_1^1=\Lambda_4^4=-\left(1+\frac{l}{2r}\right)\Lambda_2^2.$$

Generation of F Centers at Low Temperature

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MARTIENSSEN[1] has demonstrated that the α-band in KBr can be bleached by irradiating with light absorbed in the α-band. This effect has been observed at -183°C. The quantum efficiency is low and the bleaching is accompanied by a green-blue fluorescence of unspecified quantum efficiency, but designated as "lebhaft." Since the α-band is believed[2] to be associated with the production of an exciton localized at a vacant halogen-ion site, this result suggests that the shifts of nuclear coordinates and lattice oscillations stimulated, when the halogen-ions around the vacancy absorb and emit light quanta, promote sufficient diffusion for the vacancies to disappear, presumably at dislocations or in formation of aggregates without a distinctly observable band. The process appears to be associated with an ideal limiting type of point thermal "spike" accompanying the readjustment of nuclear coordinates after a change of electronic state. We shall assume that half the 6 ev absorbed is reemitted as light, and the remaining 3 ev is divided equally in thermal spikes accompanying absorption and emission. Since at least eighteen neighboring ions participate in this readjustment in a major way, and since about 1.5 ev presumably is available for vibrational quanta in each readjustment, the initial spike temperature should correspond to no more than 0.1 ev per ion, or to an average temperature of about 400°K. It is possible, however, that even this low spike temperature is adequate to promote diffusion because the equilibrium nuclear configuration for the initially degenerate excited state is close to the saddle point for the migration process in the ground state; relatively small thermal oscillations are sufficient to guarantee an appreciable probability for the jumping process each time a light quantum is absorbed in the α-band. It would be exceedingly valuable to know if the α-band formed at liquid hydrogen or helium temperatures can be bleached in the same way at these low temperatures. If this is the case, the results appear to throw penetrating light on the way in which F and V centers are generated at very low temperatures by x-rays, a problem recently reviewed by Markham.[3] The writer proposes the following speculative solutions.

(1) The x-ray quanta produce energetic photoelectrons which dissipate their energy in the formation of electrons, holes, and excitons, the agents ultimately responsible for production of color centers. Initially the electrons and holes become trapped at incipient negative- and positive-ion vacancies (jogs at Taylor-Orowan dislocations) where they may annihilate one another if sufficiently close. The excitons also end their lives at incipient vacancies[4] producing point thermal spikes analogous to those described above, only of higher intensity by a factor of three or four since a luminescent quantum is not emitted as frequently. These spikes may be violent enough to promote evaporation of incipient vacancies and thereby form normal vacancies near the dislocations. However, we shall assume tentatively that the electrons and holes present play an essential role. If not, it should be possible to produce color centers at very low temperatures by irradiating in the tail of the fundamental band, as is possible[5] at nitrogen and higher temperatures. This highly important experiment apparently has not yet been carried out.

(2) It is assumed that many incipient vacancies occur in the form of neighboring pairs of opposite sign, because of the electrostatic attraction. When one member of a pair captures an electron or hole, the two centers repell one another strongly. Such electrostatic repulsive forces, operating in conjunction with the thermal spikes, have the effect of causing incipient vacancies to evaporate, forming isolated vacancies and clusters in the region around the dislocation.[6] This gas will be more widely dispersed at liquid nitrogen temperature than at hydrogen or helium temperatures because of the higher density of thermal quanta at the higher temperature. Some of the vacancies are present in the form of coupled pairs of positive- and negative-ion vacancies, the most mobile agent containing a halogen-ion vacancy. However, pairs, like isolated positive-ion vacancies, do not contribute an absorption peak in the tail of the fundamental band.

(3) The α-band is stronger than the F band when the crystal is radiated at hydrogen temperatures (Martienssen[1] Fig. 3) because the separation of neighboring centers is sufficiently small that many electrons and holes trapped at vacancies annihilate by tunneling (see page 408 of the second reference in footnote 4 for comment on tunneling). At liquid nitrogen temperatures the vacancies become more widely dispersed, and a higher ratio of number of F to α-centers prevails. The spacing between centers is sufficiently close, if they are formed at helium temperatures, that annihilation of electrons and holes is enhanced when the electrons in the F centers are raised to the first excited state.

(4) When a coupled pair of vacancies captures an electron, the positive-ion vacancy is, with the aid of the accompanying thermal spike, expelled for several lattice spacings even at helium temperatures, as a result of the electrostatic repulsion of the electron and the positive-ion vacancy. Hence the F center formed is essentially normal. In contrast, the thermal spike is not sufficient to aid the escape of the halogen-ion vacancy, because of the higher barrier for migration. When the crystal is warmed to 78°C, the hole escapes from the pair giving the current pulse observed by Dutton.[7] The free hole is either captured by a positive-ion vacancy to form a V_1 center, or annihilates an electron at an F center. The H center of Duerig and Markham[8] is a vacancy pair on which a hole is trapped, that is, is a V_1 center to which a halogen-ion vacancy is attached.

(5) It is assumed that the density of incipient vacancies in a normal specimen is so small that the absorption arising from incipient F and V centers is not observable in crystals of normal thickness.

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[6] This solvent action of electrons and holes is described by the writer (F. Seitz) in Revs. Modern Phys. 18, 384 (1946). See p. 403ff.
[7] Dutton, Heller, and Maurer, Phys. Rev. 84, 363 (1951).
[8] W. H. Duerig and J. J. Markham, Phys. Rev. 88, 1043 (1952). The term H center is now used by these investigators to designate the new bands described on p. 1049 of this paper.