The short-circuit current, I_s, should be proportional to the number of photons absorbed in the solid. The spectral response of the cells was therefore established by observing a quantity proportional to I_s as a function of photon energy. The results of such an experiment,[6] in which the photons were supplied by a monochromator, are shown in Fig. 2. The lower curve illustrates the

TABLE I. Efficiency of various GaAs solar generators.

Unit No.	Area 10^{-2} cm^2	Solar power input mw/cm^2	Max power output μw	η_{max} %
1	5.9	83	157	3.2
2	0.7	5.7	2.6	6.5
3	0.57	40	9.8	4.3
4	0.7	42.6	15.3	5.2
5	0.12	69	4.5	5.3
6	0.2	69	7.0	4.9

response per unit energy while the upper curve gives the response per photon. As expected, the latter is reasonably constant for a wide range of photon energies. Both curves indicate a cut-off energy of about 1.35 ev which corresponds to the energy gap of GaAs as determined from its optical transmission. The absolute quantum efficiency has not been measured, but it can be estimated from the ratio of I_s to the potential value of I_s if all those photons whose energy exceeds 1.35 ev were absorbed. This ratio is about 0.4. Some of the loss can be ascribed to reflection at the front surface, while another fraction is lost by recombination of the liberated carriers either at the exposed surface or in the bulk material.

The units described in this letter have not been designed to give optimum performance, so that it is reasonable to expect an increase in the efficiency of such cells as their technology improves.

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Self-Diffusion and Conductivity in Silver Chloride*

W. DALE COMPTON†

Department of Physics, University of Illinois, Urbana, Illinois

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TRANSPORT measurements by Tubandt[1] indicate that only the silver ions are mobile in silver chloride between 20°C and 350°C. The tracer diffusion coefficient, D_T, of the silver ion, as measured with the

Ag^{110} isotope, does not agree, however, with the diffusion coefficient, D, calculated from the conductivity, σ, by the Einstein-Nernst[2] relation

$$D = (kT/Ne^2)\sigma \qquad (1)$$

where N is the number of silver ions per unit volume. The ratio, D/D_T, is 1.7.

Figure 1 shows diffusion data obtained from two portions of a silver chloride crystal.[3] The data on the upper curve represent the diffusion coefficients, D, as calculated from the measured ac conductivity by the use of Eq. (1). The data on the lower curve are the measured tracer diffusion coefficients, D_T. The measured intrinsic conductivities are in good agreement with those reported by Koch and Wagner[4] and Ebert and Teltow.[5]

The tracer diffusion coefficient of the chloride ion has been measured in AgCl by using the Cl^{36} radioisotope. Between 443°C and 324°C the measured diffusion
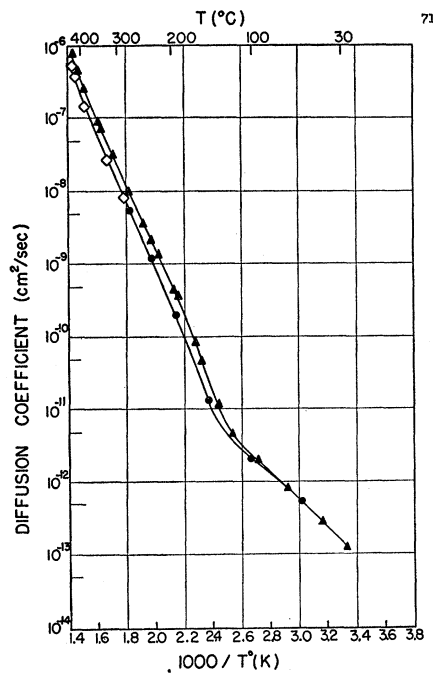

FIG. 1. Diffusion coefficients vs reciprocal absolute temperature in silver chloride. ▲—Diffusion coefficients calculated from the electrical conductivity by Eq. (1). ◇, ●—Diffusion coefficients of silver measured with Ag^{110} radioisotope. Two different sections of the same crystal were used.

coefficient of the chloride ion is about 10^{-3} that of the silver ion. The failure of the Einstein-Nernst relation cannot be explained, therefore, as the result of a contribution, undetected by transport number measurements, of the chloride ion to the conductivity.

Figure 1 indicates that, at low temperature, the Einstein-Nernst relation is satisfied by the data. The ratio D/D_T, obtained from other silver chloride crystals, has been as large as 1.25 in the low-temperature region

where the presence of accidental impurities affects the conductivity and diffusion coefficient of the silver ion. Accidental contamination of the samples during measurement may be the cause of this variation in their low-temperature behavior.

Since the mechanism of diffusion in the low-temperature impurity range is believed to be primarily due to silver ion vacancies, the data suggest that the failure of the Einstein-Nernst relation in the high-temperature intrinsic range is associated with the mechanism by which interstitial silver ions contribute to conductivity and diffusion.[5]

I wish to thank Professor Robert Maurer for his advice and assistance with this work.

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Ratio of Ionic Conductivity to Tracer Diffusion in Interstitialcy Migration

C. W. McCombie,* *Department of Physics, University of Illinois, Urbana, Illinois*

AND

A. B. Lidiard, *Atomic Energy Research Establishment, Harwell, Berkshire, England*
(Received December 5, 1955)

THE experimental results of Compton[1] suggest that, for that part of the ionic migration in AgCl crystals which is due to the presence of interstitial silver ions, the ratio of ionic conductivity to tracer diffusion considerably exceeds the Einstein value. It will be shown here that a value of this ratio about three times the Einstein value is to be expected for migration by the *interstitialcy* mechanism discussed by Koch and Wagner[2] and so described by Seitz.[3] In this mechanism an interstitial ion moves by pushing a neighboring lattice ion into an interstitial site and itself taking the place of the displaced lattice ion. The lattice site and the two interstitial positions involved are supposed collinear. If the jump distance of each of the two ions involved in such a jump is d, the interstitialcy, and so the charge, jumps a distance $2d$. Consideration of this point gives the main contribution to our result. A correlation effect of the type discussed by Bardeen and Herring[4] for vacancy diffusion also contributes.

If D_i is the diffusion constant and ν_i the jump frequency for the interstitialcies, the familar device of comparing the results of point-source diffusion and random-walk calculations gives

$$D_i = \tfrac{1}{6}\nu_i(2d)^2.$$

To obtain a corresponding expression for the tracer diffusion constant D_t, we suppose that there are N silver lattice positions and N_i interstitial silver ions. Since two silver ions are displaced in each interstitialcy jump, there will be $2N_i\nu_i$ ion jumps per second. Consequently a given tracer ion will make a jump $(2N_i/N)\nu_i$ times per second. The Bardeen-Herring correlation effect has to be considered here because successive jumps of a tracer ion, unlike successive jumps of an interstitialcy, are not independent. If the tracer has just jumped to an interstitial position the subsequent jump will indeed be random, but if it has just jumped to a lattice position the interstitialcy is so positioned that there is a relatively high probability of its causing the tracer to jump back in the direction from which it came. If $\langle\cos\theta\rangle_{\text{Av}}$ is the mean cosine of the angle between two consecutive jumps of a tracer ion when the first jump is into a lattice position, we find

$$D_t = \tfrac{1}{6}(1 + \langle\cos\theta\rangle_{\text{Av}})(2N_i/N)\nu_i d^2.$$

Thus

$$D_t/D_i = \tfrac{1}{2}(1 + \langle\cos\theta\rangle_{\text{Av}})(N_i/N).$$

The interstitialcies will themselves satisfy the Einstein relation since they will distribute themselves in an applied field according to the Boltzmann law[5]: that is

$$\sigma/D_i = N_i e^2/kT,$$

and so

$$\sigma/D_t = 2(1 + \langle\cos\theta\rangle_{\text{Av}})^{-1}Ne^2/kT.$$

Our estimate of $\langle\cos\theta\rangle_{\text{Av}}$ is about -0.33. Thus, if the migration were entirely by the interstitialcy mechanism, the observed ratio would be about three times the Einstein value. For vacancy diffusion, a Bardeen-Herring type correction alone operates and multiplies the Einstein value by only about 1.25. If we assume equal numbers of interstitialcies and vacancies, and use the values given by Ebert and Teltow[6] for the ratio of mobilities, the expected value of σ/D_t at 350°C turns out to be about 2.5 times the Einstein value; this is to be compared with Compton's experimental factor of 1.7. Both factors decrease somewhat with increasing temperature. Departures from collinearity in the two ion displacements in an interstitialcy jump, or the presence of any of several other diffusion mechanisms, could account for Compton's factor being smaller than our estimate. It is difficult to assess how likely these various possibilities are.

The effects discussed here may be useful in distinguishing experimentally between interstitialcy and vacancy migration in other crystals.