E_v, E_A, E_c, the two systems being coupled by the fact that the level E_3 has an electron associated with it. To investigate this model in detail requires a more exact specification of the states ; but it is immediately obvious that if the energy differences $E_2 - E_1$ and $E_1 - E_3$ are both large compared with kT and the entropy difference between the states is not too great then almost exact compensation will occur as long as the reservoir contains sufficient defects. In other words, it is energetically advantageous for defects to become acceptors so long as there is an electron for them to accept, but not otherwise.

An alternative possibility is that acceptors and donors form associated pairs[1], but this mechanism should lead to an increase in electron mobility, contrary to observation. Also the calculated degree of pairing is insufficient to account for the exactness of compensation found.

In the case of semi-insulating gallium arsenide it seems probable that oxygen is dissolved in the lattice in two different sites, being electrically active in one site (as an acceptor) and inactive in the other (as the reservoir). In the case of cadmium sulphide and similar compounds, the work of Kröger and Vink[2] shows clearly that the deep levels are associated with crystal defects arising from non-stoichiometry, and the reservoir of such defects is obviously the ambient atmosphere. In cadmium sulphide one can vary χ by annealing crystals at various temperatures and in various atmospheres, and similarly in gallium arsenide one should be able to vary χ by suitable heat treatment.

My model suggests that semi-insulators of the type I have described, that is, those in which a shallow donor is auto-compensated by a deep acceptor, should exhibit pronounced hole trapping effects but little electron trapping. This has a number of practical implications. For example, the high photoconductivity of these materials is readily explained. Also the existence of large space-change currents in certain crystals of cadmium sulphide[3] but not in others may be explained by variations in χ between the crystals. One might predict that semi-insulating gallium arsenide suitably heat-treated might also show such currents.

The ideas expressed here were developed while attempting to account for the experimental results of Dr. G. T. Wright on cadmium sulphide and of Dr. C. Hilsum and his colleagues on gallium arsenide. I wish to thank them both for extensive discussion of the problems involved.

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[1] Prener, J. S., *J. Chem. Phys.*, **25**, 1294 (1956).
[2] Kröger, F. A., and Vink, H. J., *Physica*, **20**, 950 (1954).
[3] Wright, G. T., *Nature*, **182**, 1296 (1958).

Gallium Arsenide for γ-Ray Spectroscopy

CRYSTAL conduction counters offer an improvement in energy resolution over ionization chambers or scintillation counters for spectroscopy of nuclear particles. Semiconductor counters which employ a p–n junction are useful only for heavy charged particles of moderate energy. For energetic charged particles or γ-rays with ranges exceeding 1 mm. of silicon a crystal with efficient charge collection throughout its bulk is required. Most crystals of sufficiently high resistivity contain so many electron traps that collection of the ionization current is inefficient, and only diamond has previously been found to count single γ-ray events. The usefulness of diamond as a crystal counter is restricted.

We have found that the semiconductor gallium arsenide with resistivity at room temperature exceeding 10^6 ohm-cm. is an efficient particle counter. When a bar of this material is bombarded with γ-radiation from cobalt-60, pulses of charge are readily observed. The time for the pulse-rise is about 5 μsec., and pulses of $0 \cdot 5$ mV. across a megohm load are seen with an applied field of 200 V./cm. This effect occurs in both n-type and p-type gallium arsenide of high resistivity. The samples used in these experiments were of dimensions 1 cm. $\times$ $0 \cdot 2$ cm. $\times$ $0 \cdot 1$ cm., but there appears to be no reason why larger crystals should not be made. We are examining the spectrum of the pulse-height and resolution of energy, and our results will be reported elsewhere.

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ENGINEERING

Pump Fluids for Higher Vacuums

IN the decade after Burch introduced petroleum oils[1] as working fluids for the Langmuir condensation pump, the silicones, octyl alcohol esters and petroleum pump fluids converged to a low-pressure optimum at about 10^{-7} mm. mercury, which the succeeding 20 years has lowered, perhaps, to 5×10^{-8} in an untrapped three-stage glass pump when measured at an ambient temperature of 25° C.

Recently, particle accelerators and the conquest of space have made demands for pressures ten or a hundred times lower, to be induced in relatively enormous containers, and it has been necessary to augment the pumps with traps filled with liquid nitrogen or helium, together with means for periodic baking out. The proliferation of apparatus occasioned by these and other alternatives is becoming far too cumbersome and expensive.

In April 1959, learning of their use as high-temperature lubricants, I began examination of a class of phenoxy benzenes and polyphenyl ethers[2] of the general formulæ :

$$(1)$$

$$(2)$$
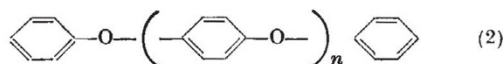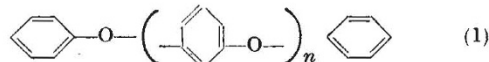
which may restore simplicity to the vapour pump. Not only can some of the compounds give pressures in the 10^{-8}–10^{-10} range untrapped, but also their tendency to wander through vacuum labyrinths is reduced many hundredfold over previously used fluids. Thus a Bayard–Alpert ionization gauge[3]