for in terms of the asymmetry in the penetrating component measured near sea level, it was concluded that there was no asymmetry in the soft component and hence that the soft component was due to equal numbers of primary positive and negative electrons. The penetrating component was identified as arising from primary protons.

Janossy and Nicolson[2] agree with this conclusion reached by Johnson, namely that the absence of a large east-west effect at high altitudes argues for two different kinds of primary particles at the equator.

The east-west effect in the penetrating component at intermediate latitudes and altitudes has recently been measured by Schein, Yngre, and Kraybill.[3] In the geomagnetic latitude range 27°–31° north, they report an asymmetry at 45° zenith angle of 0.46 ± 0.07, at a pressure altitude of 34,500 feet, in the particles that can penetrate 22 cm of lead.

In the experiment here reported the asymmetries in both the hard and soft components were measured. The telescopes were the same as used previously by us,[4] except the extreme angles were changed to include ±16° in zenith angle and ±20° in azimuth. Counting rates at the vertical with no absorber were about 500 per minute at the equator at an atmospheric pressure corresponding to 3.10 m of water (32,000 feet). The experiment was performed at approximately 0° geomagnetic latitude and 76° west geographic longitude.

Table I gives a summary of the results at 45° zenith angle. The counting rate has been corrected for dead time of the counters, accidental counts, and for side showers. An indication of the magnitude of the shower correction was obtained by displacing the center tray of counters out of line. A detailed account of these corrections will be published elsewhere.

The following conclusions are drawn from the data in Table I: (a) That at these altitudes the west excess in the total radiation is nearly as large as in the penetrating component. (b) That the percentage asymmetry is increasing with altitude. The fact that the percentage west excess is greater for the more penetrating radiation together with the fact that it decreases with decreasing altitude may be due to scattering suffered by the lower energy particles.

More complete data at the higher altitude were taken. The percentage west excess as a function of zenith angle with and without lead absorber is plotted in Fig. 1. This brings out quite clearly the near equality in the asymmetry of the penetrating and soft components.

The conclusion to be drawn is, that as far as these experiments are concerned, it is not necessary to assume a different primary particle to account for the penetrating and soft components at the equator and that it is quite likely that only one kind of incident, positively charged particle will suffice.

TABLE I. East-west asymmetry over Peru, zenith angle 45°.

M of water equivalent	Thickness of Pb absorber	West excess* (%)
3.1	0	23.3±1.1
	10	27.6±1.3
	20	30.4±1.5
2.35	0	29.1±1.4
	10	33.0±1.6
	20	35.4±1.7

* Computed from the difference between west and east divided by the average.

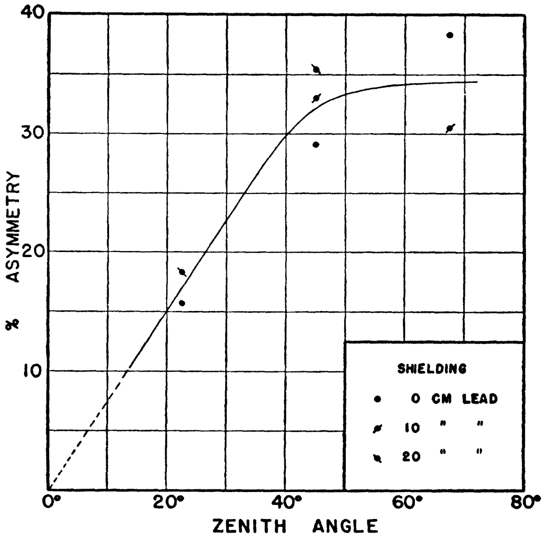

FIG. 1. The west excess in percent as a function of zenith angle with and without lead absorber.

We wish to thank the Office of Naval Research for making these flights possible. We also wish to extend our appreciation to Major W. A. Gustafson and his men of the Air Forces for their cooperation and skillful handling of the plane.

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** Data of 2.35 m of water and zenith angle of 22½° are missing for 10 cm of Pb and at 67½° for 20 cm of Pb because of lack of time.

[1] T. H. Johnson and J. G. Barry, Phys. Rev. **56**, 219 (1939).

[2] L. Janossy and P. Nicolson, Proc. Roy. Soc. **192**, 99 (1947).

[3] M. Schein, V. H. Yngre, and H. L. Kraybill, Phys. Rev. **73**, 928 (1948).

[4] Biehl, Montgomery, Neher, Pickering, and Roesch, Rev. Mod. Phys. **20**, 353 (1948).

The Double-Surface Transistor

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IN a series of Letters to the Editor[1] appearing in a recent issue of this journal, there are described the physical construction and proposed theory of operation of a solid state semiconductor triode. This device, which is now called the type *A* transistor, comprises a block of high back-voltage germanium on one of the faces of which are two contacts, side by side with each other and close together. These contacts are called the emitter and collector, respectively. A large area contact to the opposite face of the semiconductor block is called the base contact.

The present communication describes another semiconductor triode, the double-surface transistor, in which the emitter and collector contacts bear on the two opposite faces of a thin wedge or slab of semiconductor. This slab is

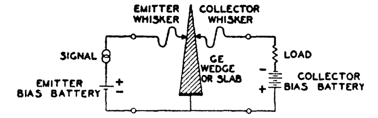

FIG. 1. Electrode geometry and circuit connections for a double-surface transistor.

prepared from an ingot of high back-voltage germanium of *N*-type.[2] After being ground approximately to the desired shape, the slab is etched and provided with a suitable large-area base contact. For good gain characteristics it is advantageous that the thickness of the slab be no greater than about 0.01 cm at the place where the contacts bear upon it. These contacts should be within about the same distance of coming exactly opposite each other on the two faces of the slab. Tungsten, copper, and phosphor bronze have been used successfully as contact materials. This device, together with its electrical connections for use as a grounded-base amplifier, is illustrated schematically in Fig. 1. In operation a comparatively large d.c. reverse bias (−50 to −100 volts) is applied to the collector, while a comparatively small d.c. forward bias (a few tenths of a volt) is applied to the emitter. Because of positive feed-back effects in the base contact and semiconductor body, the emitter bias voltage-to-base may in some cases be zero or even negative.

The static characteristics of a double-surface transistor are presented in Fig. 2. Families of collector voltage *vs.* collector current curves are given, with constant emitter current as parameter for the solid lines, and with constant emitter voltage as parameter for the dashed lines. Such a plot allows one to make judicious choice of d.c. operating point. It furnishes in addition complete information from which can be obtained, almost by inspection, the dynamic input and output impedances and the forward and backward transfer impedances of the device about any operating point selected.

In the double-surface transistor the emitter and collector points can be separated by surface paths many times longer than those in the type *A* transistor. It appears that double-surface transistor action takes place through the body of the slab rather than along its surface layers. A tentative explanation of the transfer mechanism in this case is illustrated in the energy level diagram of Fig. 3. An important part of the picture is the bending up of the energy bands of the semiconductor from *D* to *C*, either as a result of the contact potential difference between metal and semiconductor,[3] or because of the presence of partly filled surface states on the surface of the semiconductor.[4] It is postulated that the bending up is sufficient to make the topmost levels of the filled band in the germanium accessible for the entry of positive holes from the conduction levels of the emitter metal. The potential of the interior of the semiconductor slab in the neighborhood of *D* is held at or near the base potential by the low resistance electrical path to the base. Application to the emitter of a positive bias with respect to the base decreases the depth of the barrier from *C* to *D* and increases the flow of holes past *D* into the interior of the slab, whence they are swept away by the collector field. Modulation of the hole current to the collector is thus secure by modulation of the emitter voltage.

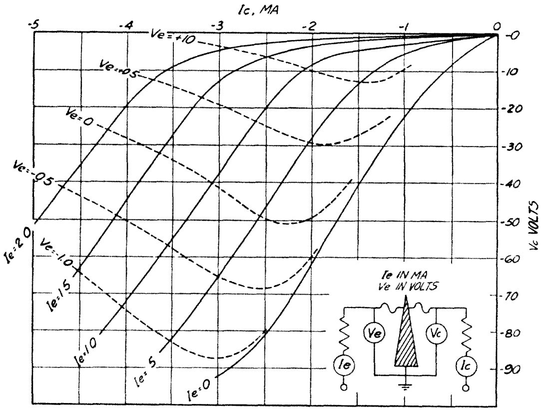

FIG. 2. Static characteristics of a double-surface transistor.

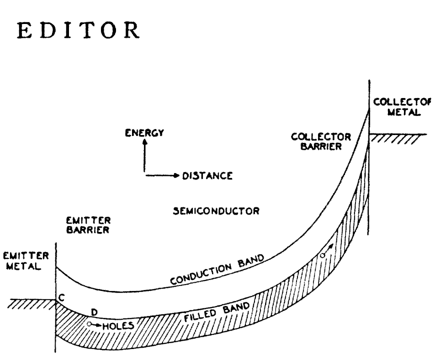

FIG. 3. Energy level diagram illustrating theory of double-surface transistor operation.

A large part of the useful gain of the device is voltage gain resulting from the introduction of current from the emitter at comparatively low impedance and its subsequent withdrawal by the collector at comparatively high impedance. In some regions of the characteristic there is observed also a current amplification $\partial I_c/\partial I_e|V_c$ of magnitude greater than unity. For the example of the unit described in Fig. 2 this current amplification is about 1.5 throughout the useful operating region. Some of this multiplication may be caused by ionizing collisions by holes in transit through the field at the collector barrier, and some by the alteration of this barrier field by the positive hole space charge in such a way as to increase the field emission of electrons from the collector.

The impetus for this development was supplied by the transistor discoveries by J. Bardeen, W. H. Brattain, and W. Shockley. To these men, and to J. A. Becker, the author is indebted for stimulating associations and discussions.

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[1] J. Bardeen and W. H. Brattain, Phys. Rev. **74**, 230 (1948); W. H. Brattain and J. Bardeen, Phys. Rev. **74**, 231 (1948); W. Shockley and G. L. Pearson, Phys. Rev. **74**, 232 (1948).

[2] The ingot was prepared by J. H. Scaff and H. T. Theuerer according to the method generally described in H. C. Torrey and C. A. Whitmer's *Crystal Rectifiers* (McGraw-Hill Book Company, Inc., Chapter 12, New York).

[3] N. F. Mott, Proc. Camb. Phil. Soc. **34**, 568 (1938); W. Schottky, Zeits. f. Physik. **113**, 367 (1939); see also Reference 2, Chapters 3 and 4.

[4] John Bardeen, Phys. Rev. **71**, 717 (1947).