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Nobel Prize in Physics 1956

William Bradford Shockley

John Bardeen

Walter Houser Brattain

The Nobel Prize in Physics 1956 was awarded jointly to William Bradford Shockley, John Bardeen and Walter Houser Brattain *"for their researches on semiconductors and their discovery of the transistor effect"*.

RESEARCH INFORMATION:

In these days 250 years have elapsed since Benjamin Franklin was born: the printer and educator, the statesman, the pioneer in the field of electricity. It was Franklin who strung a high-tension line from a thundercloud to a green pasture in idyllically rural Philadelphia. He showed that the cloud held electric energy. A kite drew energy out of the cloud. The kite string was drenched by the rain and therefore conducted the charge down to a key, which gave off sparks when approached too closely. Franklin had tied one end of a silk ribbon to the key; he clutched the other end of the ribbon as he stooped under a cowshed to keep his silk insulator dry.

A conductor and an insulator was what Franklin needed for his power line. Electrical engineering would have been unthinkable today if Nature had not presented the material in these two extreme classes, metallic conductors and insulators. Mobile carriers of charge are almost entirely lacking in an insulator, but a good conductor has plenty of them, about one for each atom. As early as 100 years ago they carried the current in the first Atlantic cable from the Old World to the New - in a fraction of a second. A group of charged carriers enters at the European end, and immediately afterwards carriers emerge from the American end - but not the same group. Over the entire length of the cable, carriers are standing tightly packed. The emigrants must push to make room for themselves at the very entrance. This push darts as a shock with the speed of light down the long line of carriers finally ejecting those that are standing next to the exit in America. Charge is therefore transported with lightning speed, although each carrier only moves a short distance. In the old days, carriers were thought to be of two kinds, positive and negative, moving in opposite directions. Franklin held that only one kind was needed. Franklin's contention was supported by the great discoveries around the year 1900. The carriers in metallic conductors are electrons, and they all carry the same negative charge.

If the Easter pilgrims in Piazza San Pietro were to represent the carriers in a metal, then an insulator would resemble the Antarctic with one solitary traveller. In the abundance of carriers there is an enormous gap between conductors and insulators. In this gap it is now possible to place the semiconductors, with carriers about as numerous as the longshoremen in a harbour when a loaded freighter has just arrived. The semiconductors now in use are artificial products made from elements such as germanium or silicon. The pure element has very few carriers. Through small additions of certain contaminants, however, it is possible to alter the supply of carriers. Every atom of phosphorus, forced as a lodger on silicon, donates one carrier to the house, a negative electron. A few parts in 100,000 make a good semiconductor. Still more remarkable is that a guest atom of boron provides a carrier of the opposite kind - positive. This the guest manages to accomplish by stealing an electron which his host, silicon, had kept locked up. Where that electron was, a hole is now left. This hole can migrate in the semiconductor, and it then acts as a carrier of positive charge.

It is possible to have both holes and electrons as carriers in a semiconductor at the same time. Donors and thieves are lodged in such proportions that one kind of carrier, or the opposite kind, will prevail. Much of the technical importance of semiconductors stems from the interplay of holes and electrons. The idea of two kinds of carriers is contrary to Franklin's views. This idea was put forward in the 1930's, at a time when rectifiers based on semiconductors began to find important uses. Attempts were made to control these rectifiers by means of an extra electrode, just as a radio valve is controlled by the grid - without success. Finally, in 1948, the discovery of transistor action gave Shockley, Bardeen, and Brattain the key to the control mechanism and, in addition, a new weapon for tackling the semiconductor problems.

The description must now borrow a picture from the classical books of adventure. To place a negative electrode against a semiconductor with negative carriers - this is like bringing a ship up to a quay in the Orient, with the yellow flag of the plague hoisted. The place becomes deserted by its carriers. Unloading - current - is blocked. But exchange that negative flag of pestilence for a positive sign and the carriers will return, the contact becoming conducting. Electrically this is called rectification. In those seafaring tales it was perhaps possible to induce the carriers to return, without striking the flag, merely by throwing some gold coins on the quay, thus positively destroying the insulation. It is possible to destroy the blockade in the semiconductor in a similar fashion by throwing in some positive holes around which the negative carriers will gather. This is transistor action. It is a fine thing that the carriers' strike can be broken up by rather few holes, which do not cost much energy. Thus the current in the rectifier is controlled through the injection of holes. A transistor functions much like a radio valve. But it is smaller, and it does not require current to heat a filament. Hearing aids, computing machines, telephone stations and many others are in need of just such a device.

The physicists at Murray Hill decided to map out that region, poor in carriers, near a negative electrode, using a movable probe at the surface of the semiconductor. This is done in the same fashion as electric prospecting for ore, but the scale is a different one. Bardeen and Brattain moved their tiny probe under the microscope, using a micrometer screw. When the probe was made positive quite close to the electrode they found that the blockade was lifted. The probe acted as an injector of holes. Shockley and his collaborators hastened to utilize this injector in a series of ingeniously conceived experiments, which then disclosed many properties of holes: how fast they travel, how long they live and other characteristics. With new tools such as these, semiconductor physics is today a seething field of research.

From Philadelphia's old pasture to today's Murray Hill is not many miles - but 200 years. Evidently there is more than the geographical proximity that connects Franklin's work with the discoveries of his latter-day country men

Doctor Shockley, Doctor Bardeen, Doctor Brattain. The summit of Everest was reached by a small party of ardent climbers. Working from an advance base, they succeeded. More than a generation of mountaineers had toiled to establish that base. Your assault on the semiconductor problem was likewise launched from a high-altitude camp, contributed by many scientists. Yours, too, was a supreme effort - of foresight, ingenuity and perseverence, excercised individually and as a team. Surely, supreme joy befalls the man to whom those breathtaking vistas from the summit unfold. You must have felt it, overwhelmingly. This joy is now shared by those who laboured at the base. Shared, too, is the challenge of untrodden territory, now seen for the first time, calling for a new scientific attack.

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