Japan Academy Prize to:

Shinji KAWAJI

Professor Emeritus, Gakushuin University

for "Experimental Studies of Two-Dimensional Electron Systems"

Outline of the work:

Professor Shinji Kawaji has consistently carried out researches on electrical conduction on the surface of semiconductors and made very significant contributions both to fundamental physics and to the basis of semiconductor technology. As electrons move two-dimensionally on the surface, he realized two-dimensional electron systems, which had hitherto been only the object of theoretical study. With these systems he discovered two new phenomena: the quantum Hall effect and the negative magneto-resistance.

1. Quantum Hall effect

In general, electrons pile up in the boudary plane of a metal-semiconductor junction and move two-dimensionally in it. When one applies a magnetic field perpendicularly to the plane and causes the electric current to flow parallel to the plane, there occurs a voltage that is perpendicular to both. This is called the Hall effect. The current divided by the voltage is called Hall conductance. Prof. Kawaji found that, at low temperatures and under a high magnetic field, the value of the Hall conductance is expressed e^2i/h, where h is the Planck constant, e the electron charge, and i an integer. This is called the quantum Hall effect. This effect is surprising in the sense that the value of the Hall conductance does not depend on either the size or material of the sample but rather only on the universal constants. This study gave rise to a large number of theoretical works aimed at explaining the quantum Hall effect. The study also attracted the attention of researchers in fundamental physics, because e^2/h divided by the velocity of light is the hyperfince constant, a quantity important in fundamental physics. As an application, the quantum Hall effect is a suitable standard for electrical resistance, being independent from the details of the sample. In fact, in 1990, the quantum Hall effect was adopted as the world-wide standard of electrical resistance.

2. Negative magneto-resistance

Prof. Kawaji further studied the magneto-resistance of two-dimensional electron systems. When a magnetic field is applied perpendicularly to the plane where an electric current is flowing, the electrical resistance of the plane increases as a result of Lorentz force which turns aside the current flow. This is called positive magneto-resistance. To the contrary, in the case of electrons in the boudary layer of Si-MOS, Prof. Kawaji found that the resistance decreases when the magentic field is applied perpendicularly to the boudary layer. He also found that, for smalll magnetic field, the resistance decreases in proportion to the square root of the magnetic field. This is called negative magneto-resistance. Furthermore, he observed that, when the magnetic field is not perpendicular to the layer, only the component of the magnetic field perpendicular to the layer contributes to the effect. This fact implies that the effect is not due to the spin of the electron but rather to the orbital motion of it. These findings also gave rise to many theoretical works aimed at explaining negative magneto-resistance. An effort by theoretical people showed that negative magneto-resistance is caused by Anderson localization, which states that the electron waves do not propagate due to interference of waves scattered by impurities. Hence, Anderson localization has the effect of increasing the electrical resistance. When a magnetic field is applied, the electron wave acquires a phase. As a result, the interference of waves is destroyed and the electron wave begins to propagate. This is why electrical resistance decreases when a magnetic field is applied. The fact that negative magneto-resistance is observed is, in turn, evidence of Anderson localization. In other words, Prof. Kawaji's experiment proved the actuality of Anderson localization. Anderson localization was studied intensively in the 1980's; and it may be said that Prof. Kawaji's work touched its core.

The quantum Hall effect and the Anderson localization in two dimension are two of the five important discoveries made in solid state physics in the 1980's. Professor Kawaji made a tremendous contributions in the sense that he took the initiative in these fields.

References

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