Josephen Effect AC & DC

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Josephson Effect :

When a thin insulating layer is sandwiched between two metals, it acts as a potential barrier for the flow of electrons from one metal to another. Quantum mechanically electrons can tunnel across a thin potential barrier and in thermal equilibrium this continues until the chemical potential of electrons in both metals become equal.

When a potential difference is applied across the metals, more electrons tunnel through the insulating layer. The current-voltage relation across the junction is observed. (fig).

If one of the metals is a superconductor (Figure), no current flows across the junction until the potential reaches a threshold value. Threshold potential is half the energy gap in the superconducting state. Threshold potential helps to calculate the energy gap of superconductor.

As the temperature increases to T_c, more excited electrons are generated. Since they required less energy to tunnel, the threshold voltage decreases. ∴ the energy gap decreases.

The current voltage relation is shown in Figure.

If both the metals are superconductors in addition to normal electrons, the super electrons (cooper pair) not only can tunnel through the insulating layer from one to another without dissociation, even at zero potential difference across the junction, also their wave functions on both sides are highly correlated. This is known as Josephson Effect.

The current voltage relation is shown in Figure. The tunnelling current across the junction is very less.

D.C. Josephson Effect :

The effect of the insulating layer is introduce a phase different $\Delta\phi$ between the two parts of the wave function on opposite sides of the junction.

The tunnelling current is

$$I = I_0 \sin(\phi_0)$$

Where I_0 is the maximum Current that can flow through the junction without any potential difference across it. And it depends on the temperature and the structure of the junction.

With no applied voltage, a dc current flows across the junction with the magnitude between I_0 and $-I_0$. And the phase different $\phi_0 = (\phi_2 - \phi_1)$. This is called d.c. Josephson effect.

A.C. Josephson effect :

If a state potential V_0 is applied across the junction, an additional phase different $\Delta\phi$ is introduced by the cooper pair during tunnelling across the junction.

ie $\Delta\phi = \frac{Et}{\hbar}$

Where E is total energy of the system, $E = (2e)V_0$

$$\Delta\phi = \frac{2eV_0 t}{\hbar}$$

$$\therefore I = I_0 \sin(\phi_0 + \Delta\phi)$$

$$= I_0 \sin(\phi_0 + \frac{2eV_0 t}{\hbar})$$

$$= I_0 \sin(\phi_0 + \omega t)$$

$$\therefore \omega = \frac{2eV_0}{\hbar}$$

This represent an alternating current with angular frequency ω. This is called a.c. Josephson effect.

When an electron pair crosses the junction a photon of energy $\hbar\omega = 2eV_o$ is emitted or absorbed. By measuring the voltage and frequency, the fundamental constant $\frac{e}{h}$ can be obtained.

(i) When $V_o = 0$, a constant d.c. current i_c flows through the junction. This current is superconducting current and the effect is the d.c Josephson effect.

(ii) So long $V_o < V_c$ a constant d.c current i_c flows.

(iii) When $V_o > V_c$, the junction has a finite resistance and the current oscillates with a frequency $\omega = \frac{2eV_0}{\hbar}$. This is a.c Josephson effect.

Applications of Josephson effect :

(i) Josephson effect is used to generate microwaves with frequency $\omega = \frac{2eV_0}{\hbar}$

(ii) A.C Josephson effect is used to define standard Volt.

(iii) A.C. Josephson effect is used to measure very low temperature based on the variation of frequency of the emitted radiation with temperature.

(iv) A Josephson junction is used for switching of signals from one circuit to another.