

# Magnetic Sensor (3C)

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- Josephson Effect
- Magnetic Flux Quantum
- SQUID sensor

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# Tunnel Junction

## The SIS-junction

- 2 bulky superconductors
- separated by a thin *insulating layers*

## Cooper pair

- a weak *attraction* between electrons in crystal
- electrons with *opposite* spin and momentum
- free particle wave function model

Cooper pairs may tunnel through the layer

→ current flows

# DC Josephson Effect (1)

## DC Josephson Effect

- **constant current** ( $I < I_c$ )
- **Cooper pairs** on each side of junction
- **penetrating** into insulating region
- **locking together** in phase

*Current* proportional to the *phase difference* of the wavefunctions can flow in the junction *without a voltage drop*.

$$I = I_c \sin \theta$$

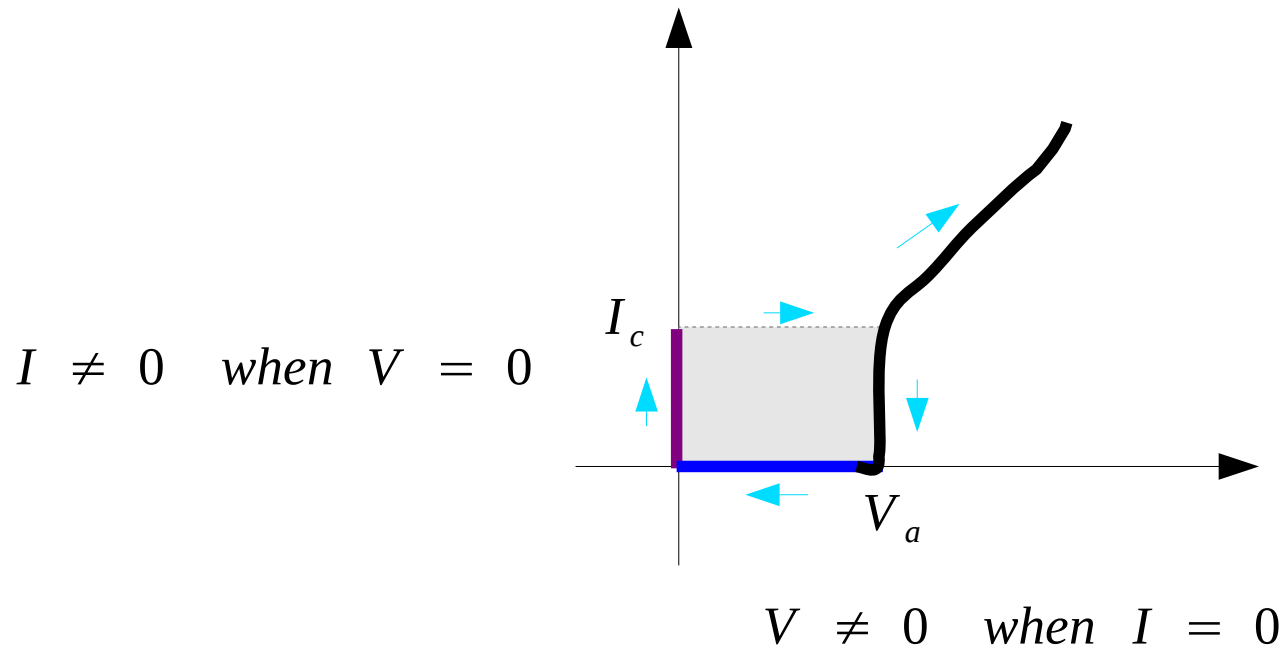
$$R = 0 \rightarrow V = IR = 0$$

$$I \neq 0 \quad \text{when} \quad V = 0$$

$$V \neq 0 \quad \text{when} \quad I = 0$$

# DC Josephson Effect (2)

## DC Josephson Effect



# AC Josephson Effect

## AC Josephson Effect

- **when DC voltage is applied to the junction**
- **Oscillation of Josephson frequency at the junction**
- *The phase varies linearly with times*
- *The current is AC*

$$\frac{d\theta}{dt} = \frac{2qV}{h} = f \quad V = \frac{h}{2q} \frac{d\theta}{dt}$$

$$I(t) = I_c \sin\left(\frac{2qV}{h} \cdot t\right)$$

**AC current**

$$I = I_c \sin \theta$$

**DC current**

# Flux Quantization

## The magnetic flux

- through a bulk superconducting loop
- Quantized in units of  $\Phi_0$

$$\phi = n \cdot \Phi_0 = \frac{n \cdot h}{2e}$$

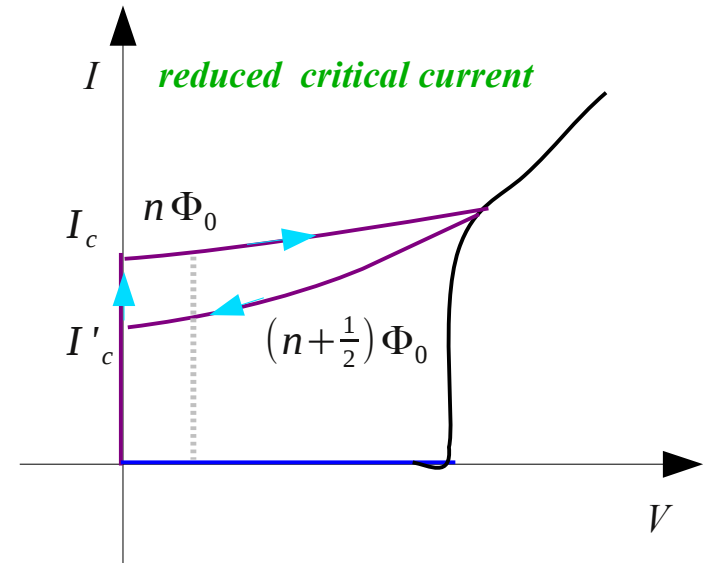
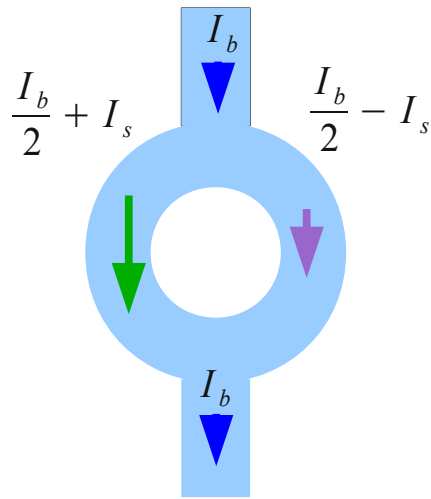
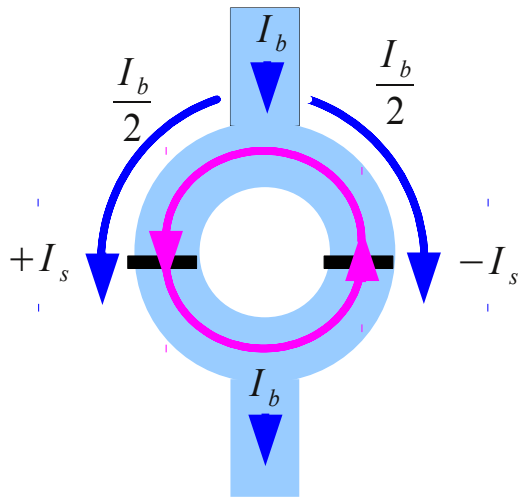
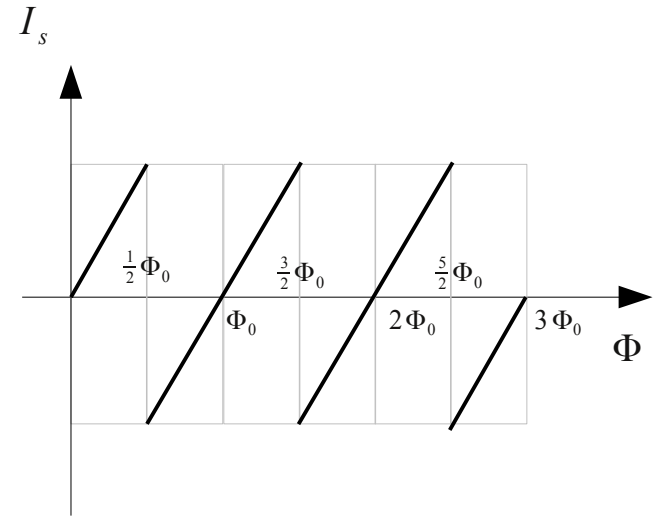
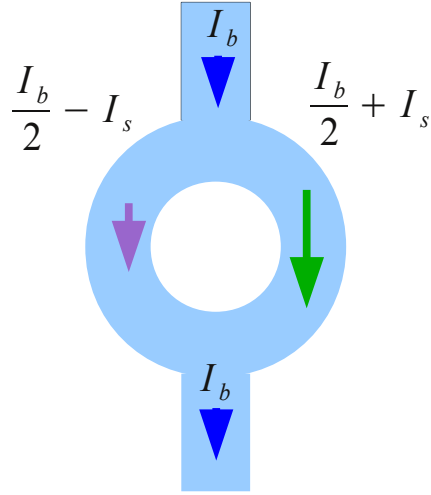
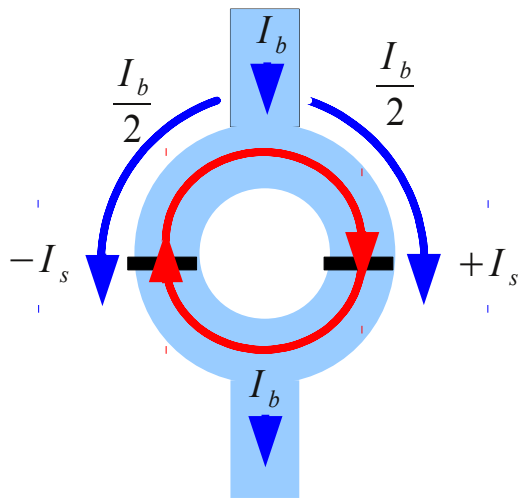
## Magnetic Flux Quantum

- min magnetic flux:  $\Phi_0$

$$\Phi_0 = \frac{h}{2e}$$

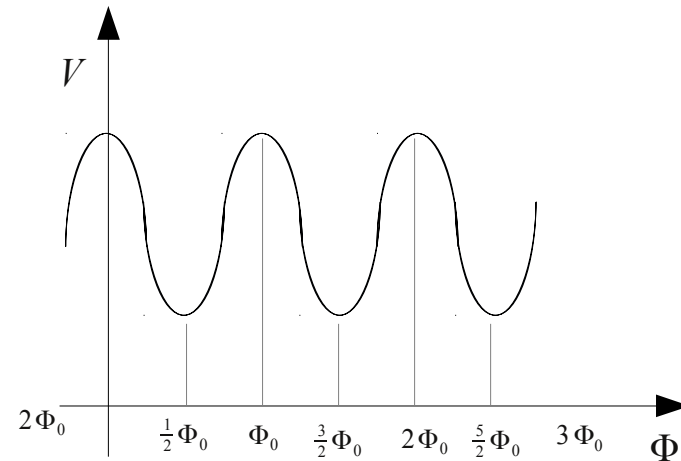
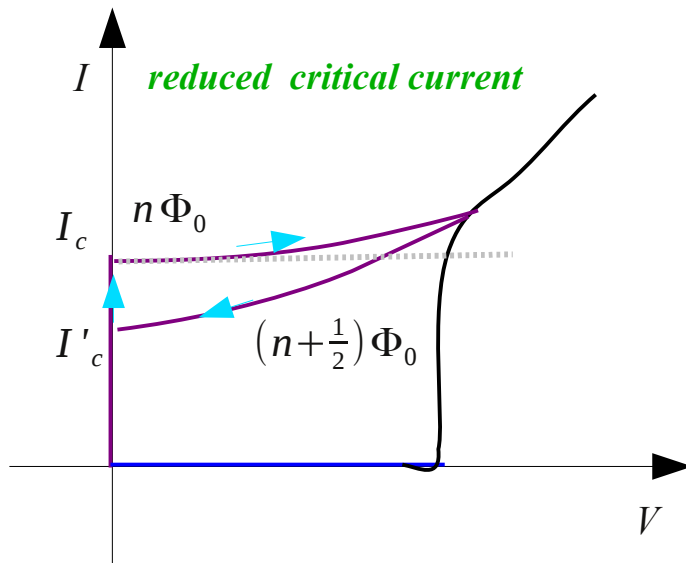
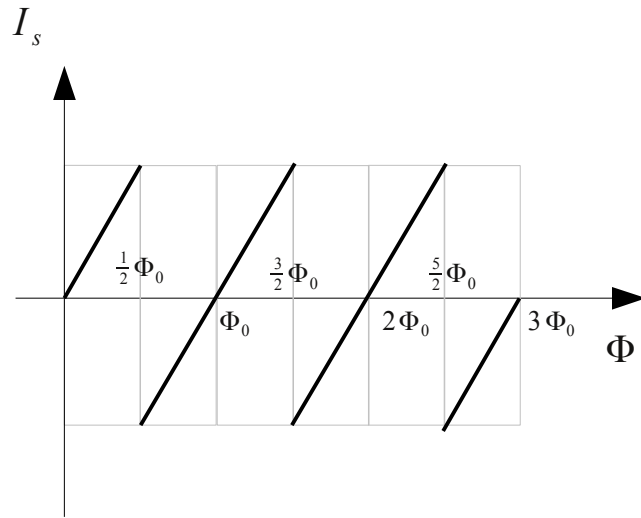
$$\frac{d\theta}{dt} = \frac{2qV}{h} = f$$

# SQUID – Screening Current





# SQUID – Periodic Dependence



## References

- [1] <http://en.wikipedia.org/>
- [2] Nam Ki Min, Sensor Electronics, Dong-il Press
- [3] <http://www.sensormag.com/> articles