Historic transducers: Balanced armature receiver (BAR)

Noori Kim and Jont B. Allen
University of Illinois, Urbana-Champaign
Electrical & Computer Engineering Dept.

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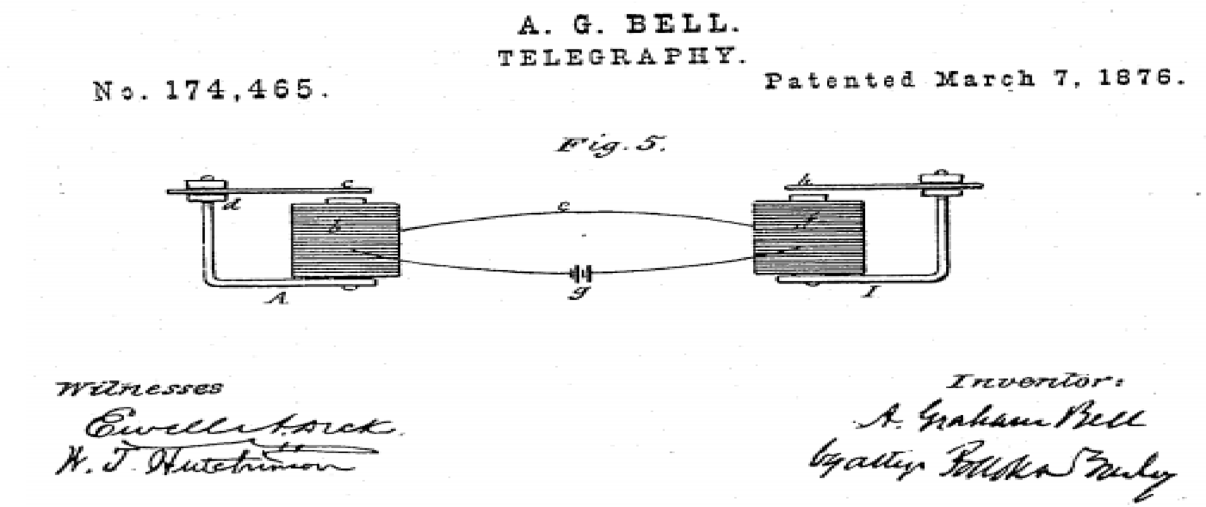
Balanced Armature Receiver (BAR)

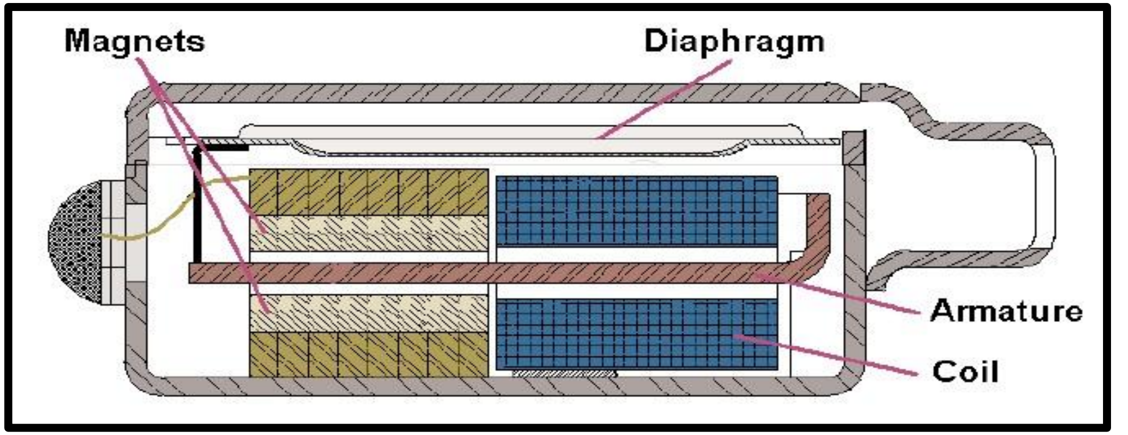
- The oldest telephone receiver is invented by A. G. Bell in 1876



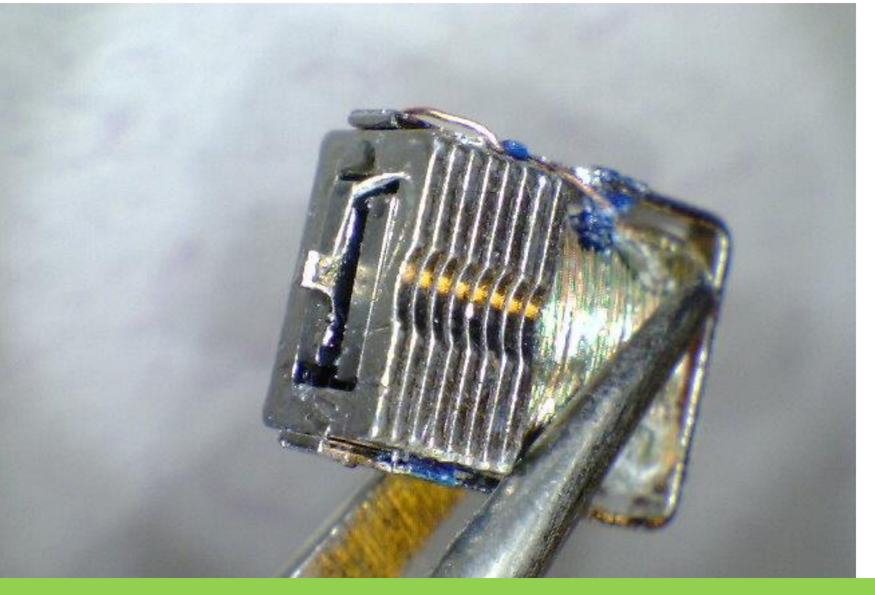
A. G. Bell, U.S. paent in 1876

- Attraction and release of the armature are controlled by the current from the coils, which generates electromagnetic fields
- Has evolved into the modern hearing-aid devices

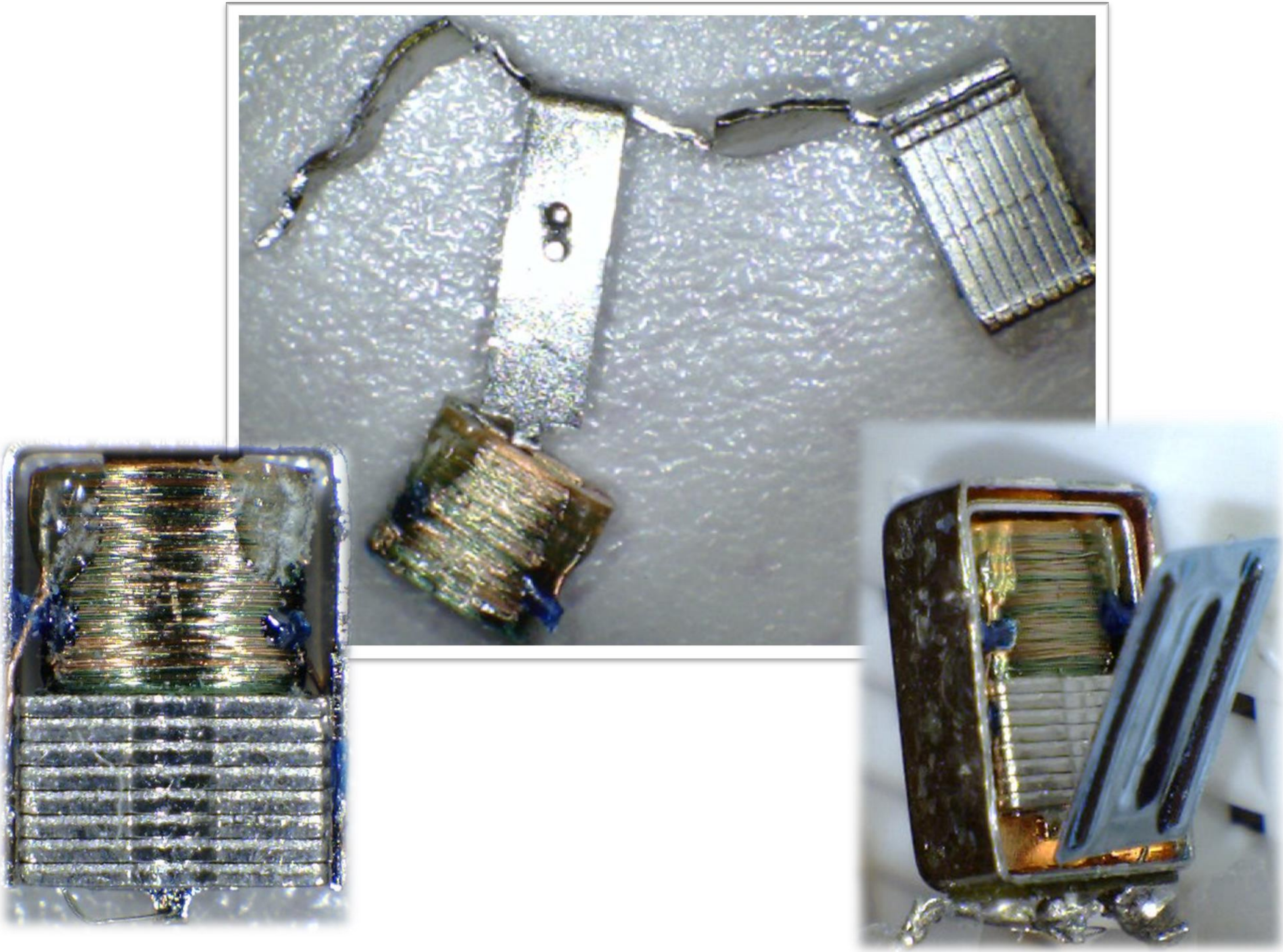
An example of the modern style BAR, Knowles ED7045



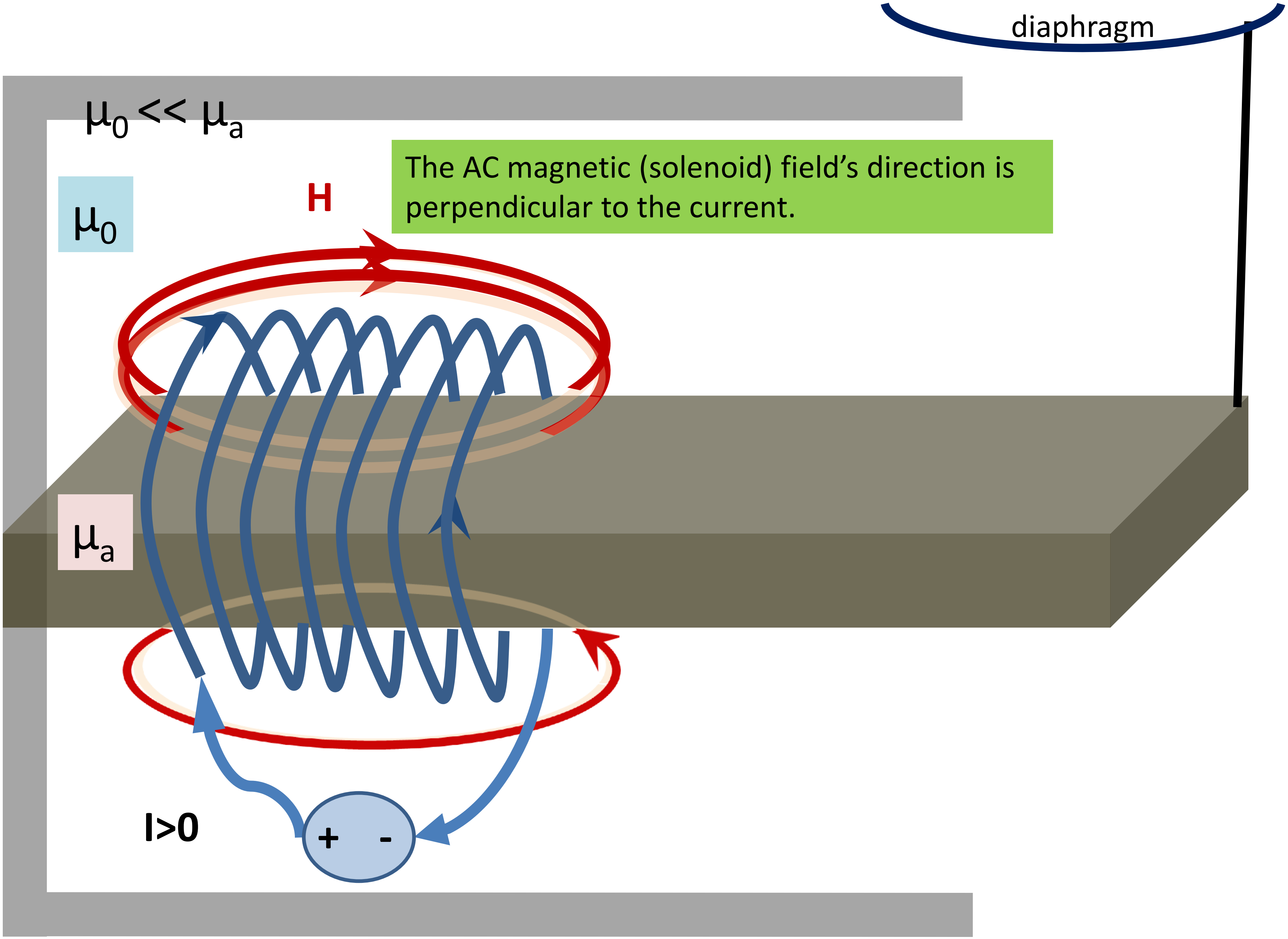
Cross section of Knowles ED receiver

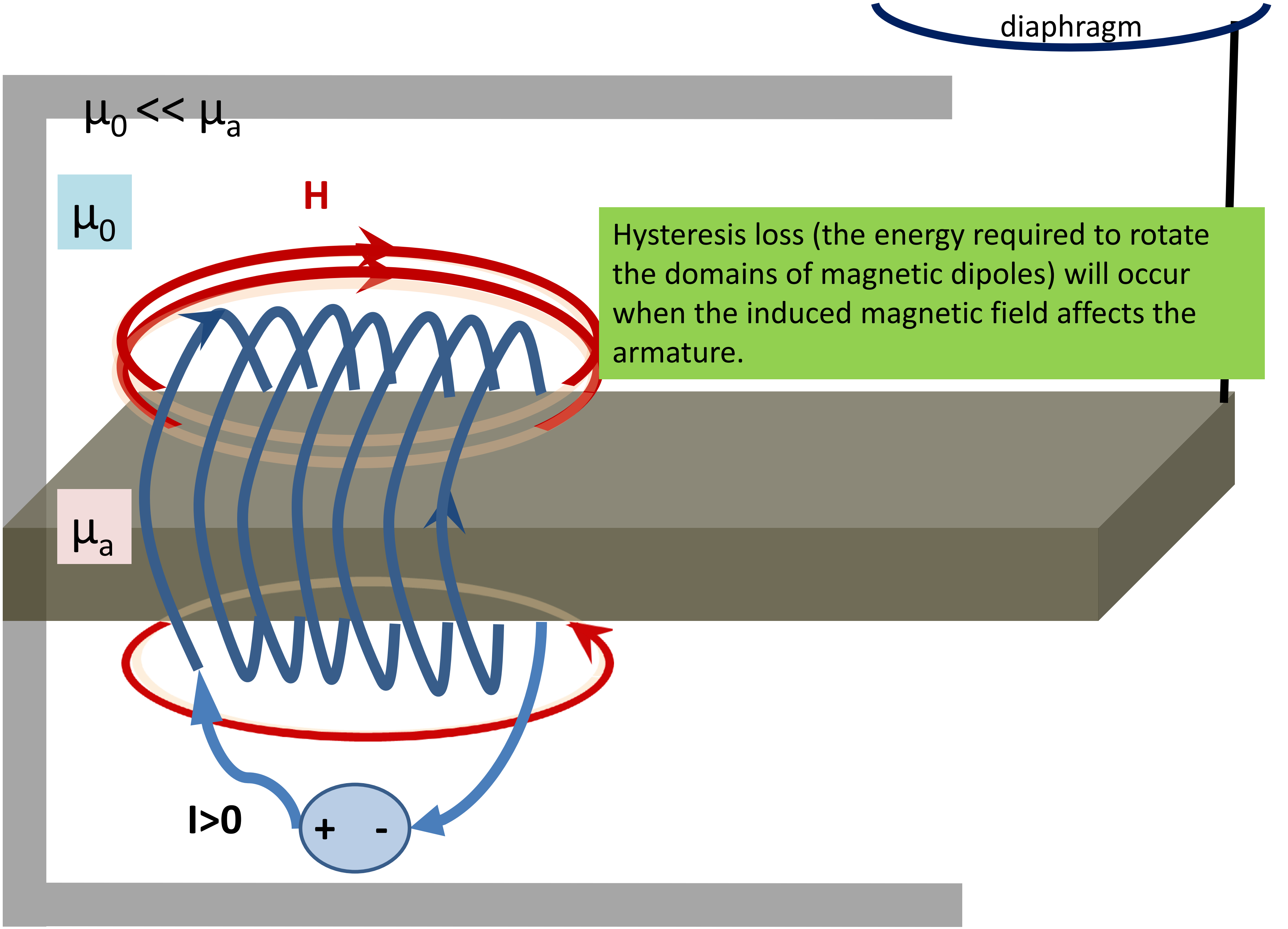


Inside of the BAR without case and diaphragm

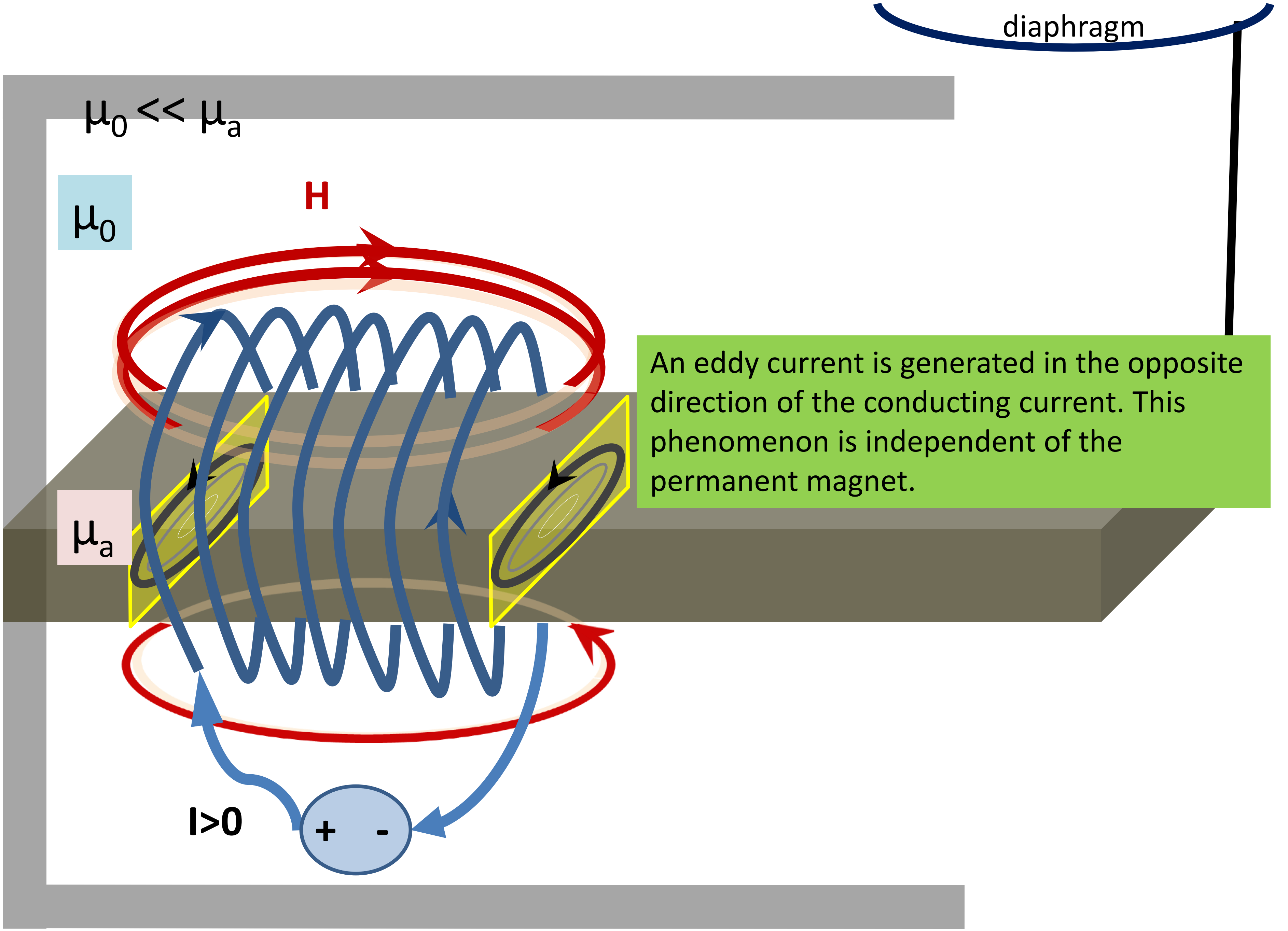


Overview of the BAR’s operation

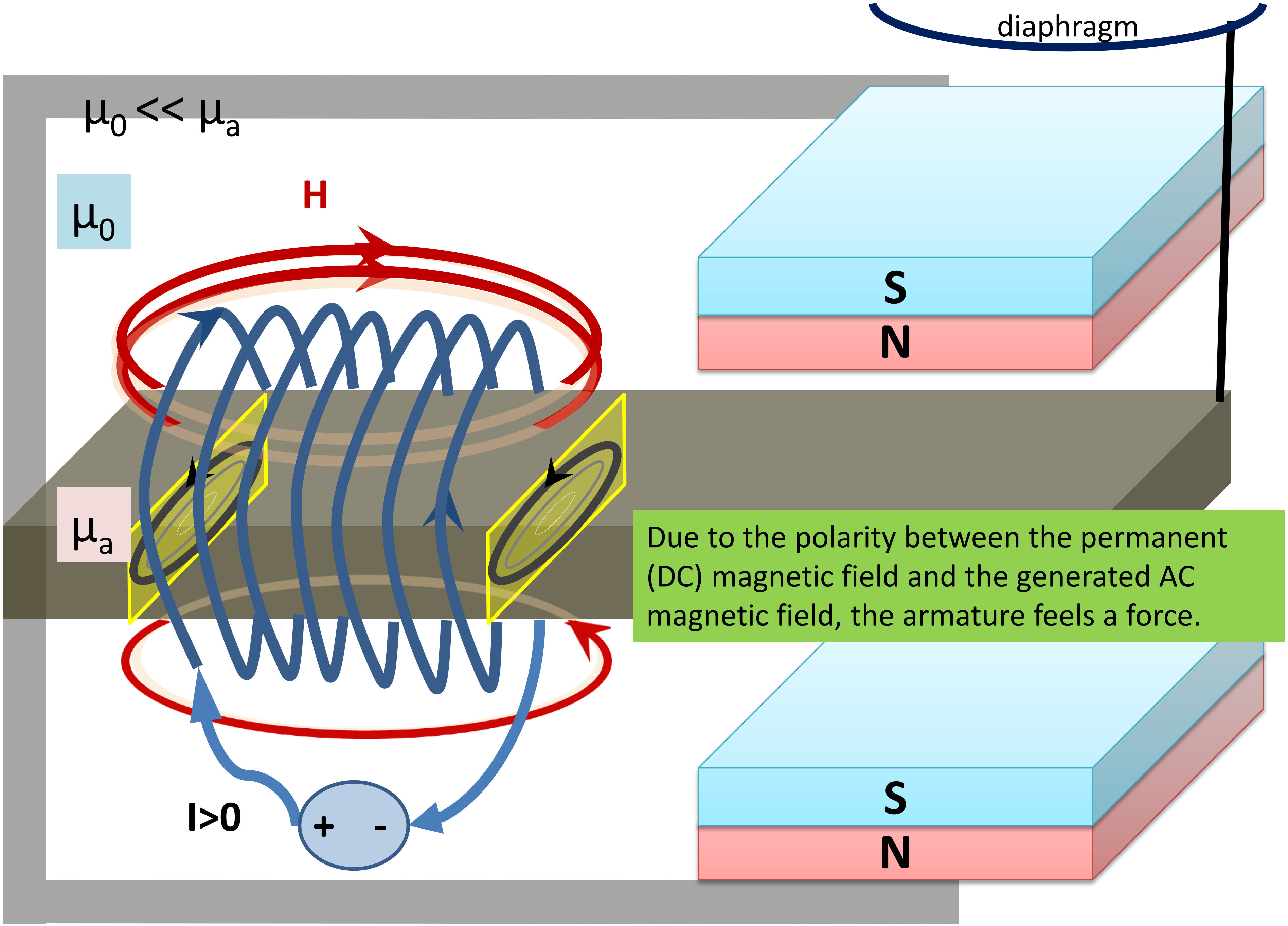

diaphragm
$\mu_0 << \mu_a$
The AC magnetic (solenoid) field's direction is perpendicular to the current.
H
μ_0
μ_a
I>0
+
-



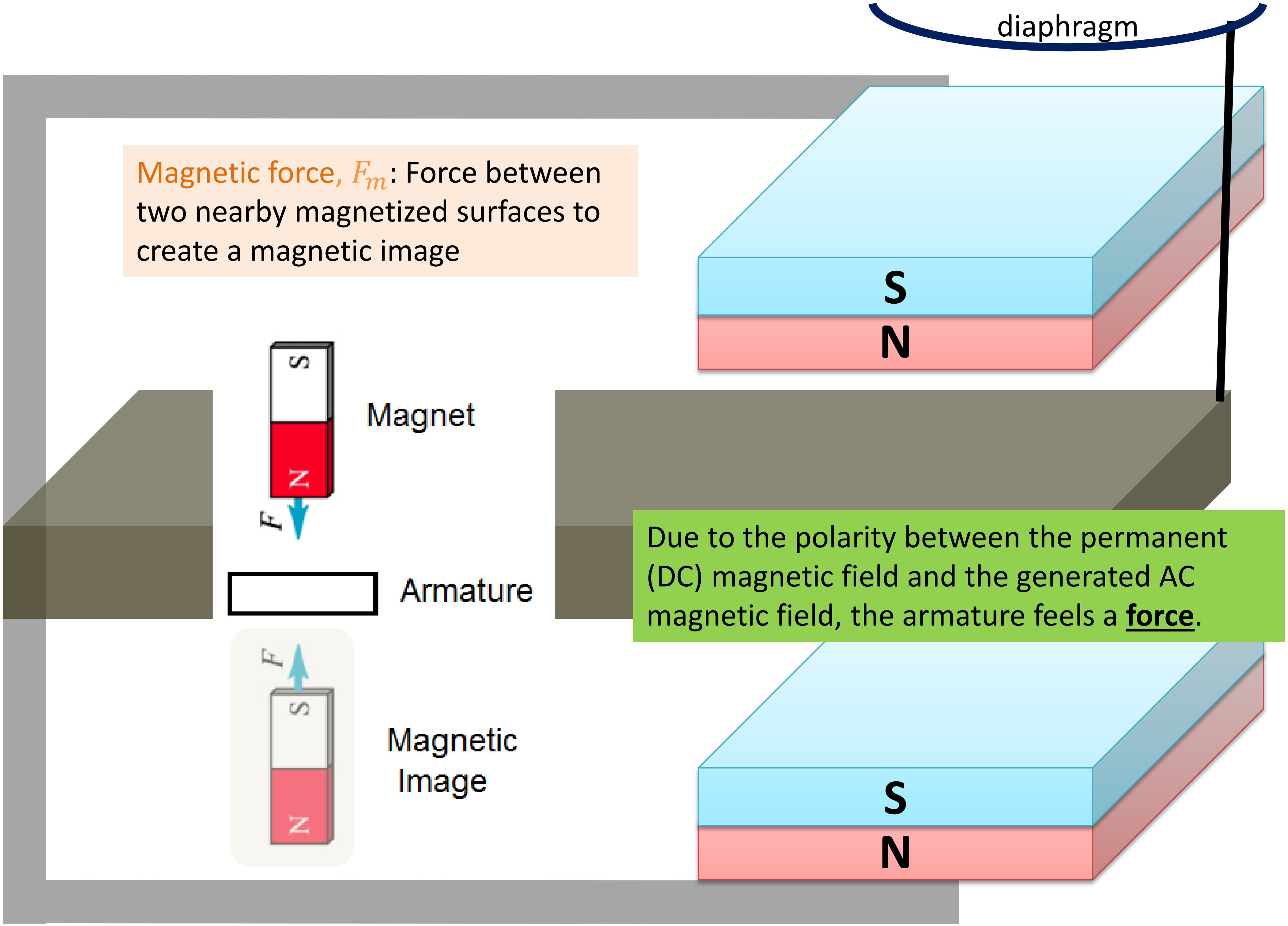
diaphragm
$\mu_0 << \mu_a$
μ_0
H
Hysteresis loss (the energy required to rotate the domains of magnetic dipoles) will occur when the induced magnetic field affects the armature.
μ_a
I>0
+
-



diaphragm
μ0 << μa
μ0
H
μa
An eddy current is generated in the opposite direction of the conducting current. This phenomenon is independent of the permanent magnet.
I>0
+
-

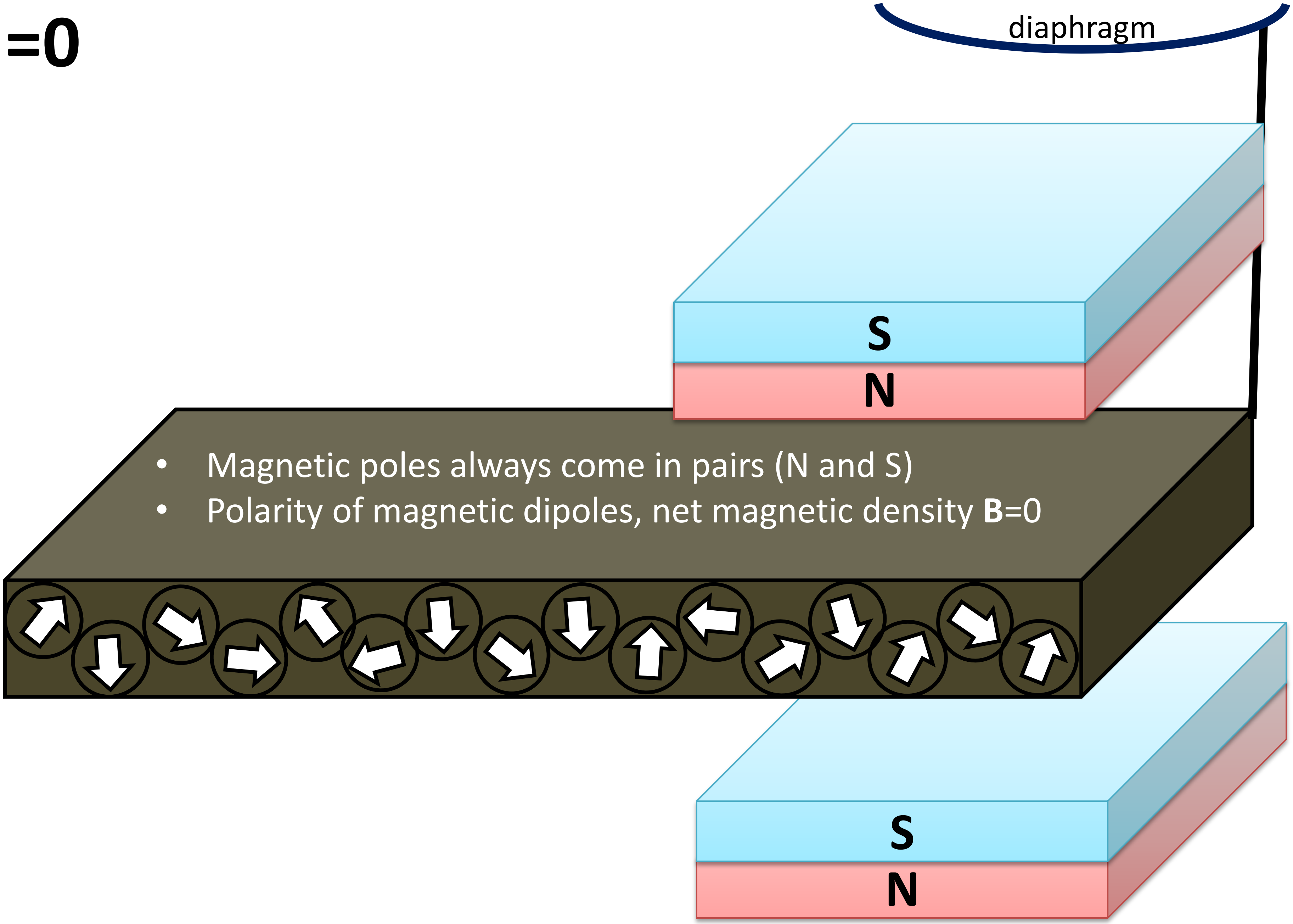


diaphragm
$\mu_0 << \mu_a$
μ_0
H
S
N
μ_a
Due to the polarity between the permanent (DC) magnetic field and the generated AC magnetic field, the armature feels a force.
S
N
I>0
+
-

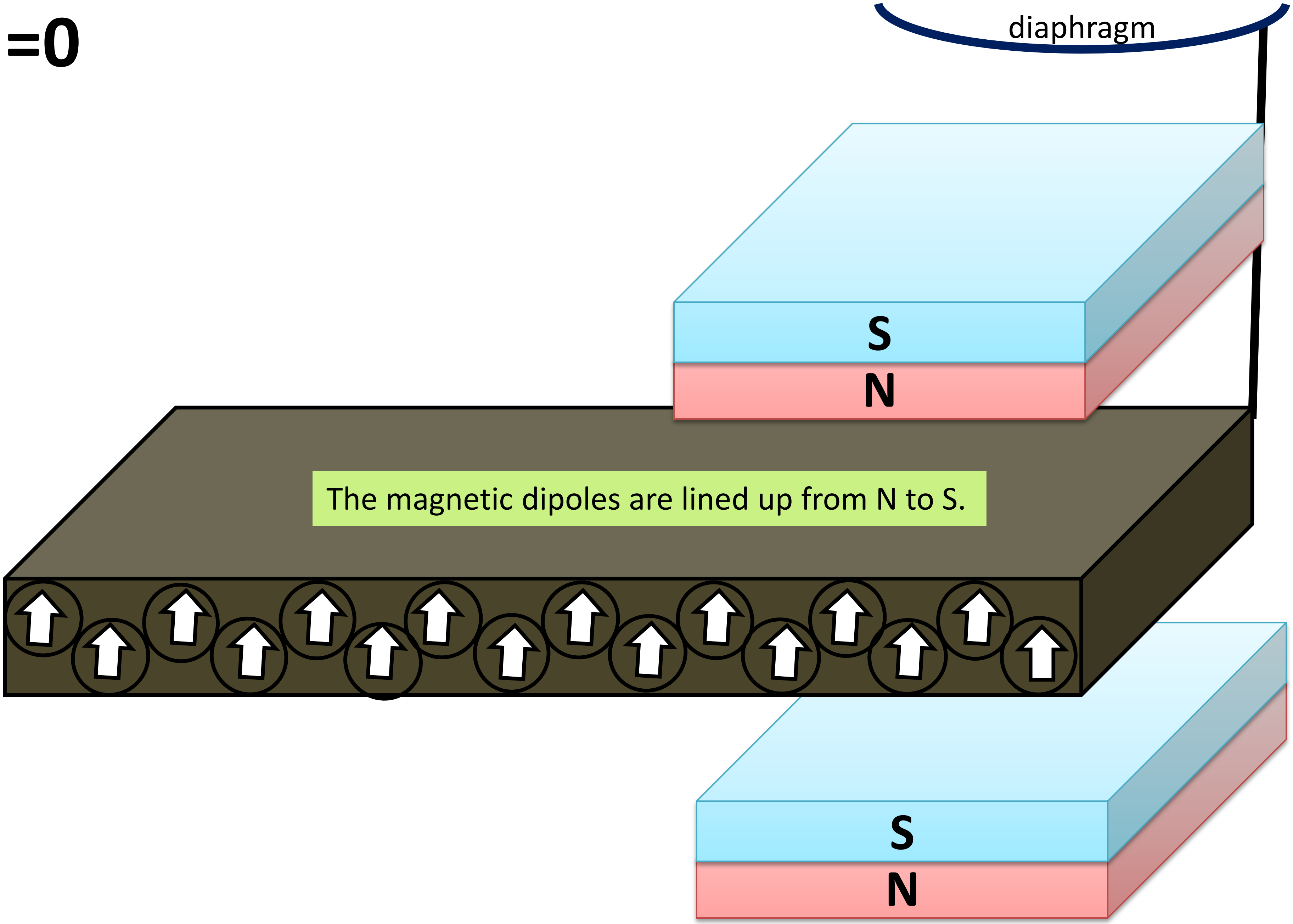

diaphragm
Magnetic force, F_m: Force between two nearby magnetized surfaces to create a magnetic image
S
N
S
N
Magnet
F
Armature
F
S
N
Magnetic Image
Due to the polarity between the permanent (DC) magnetic field and the generated AC magnetic field, the armature feels a **force**.
S
N

Illustrative case studies of the BAR: $\mathrm{I} = 0$ and $\mathrm{I} \neq 0$ (Eddy-currents)

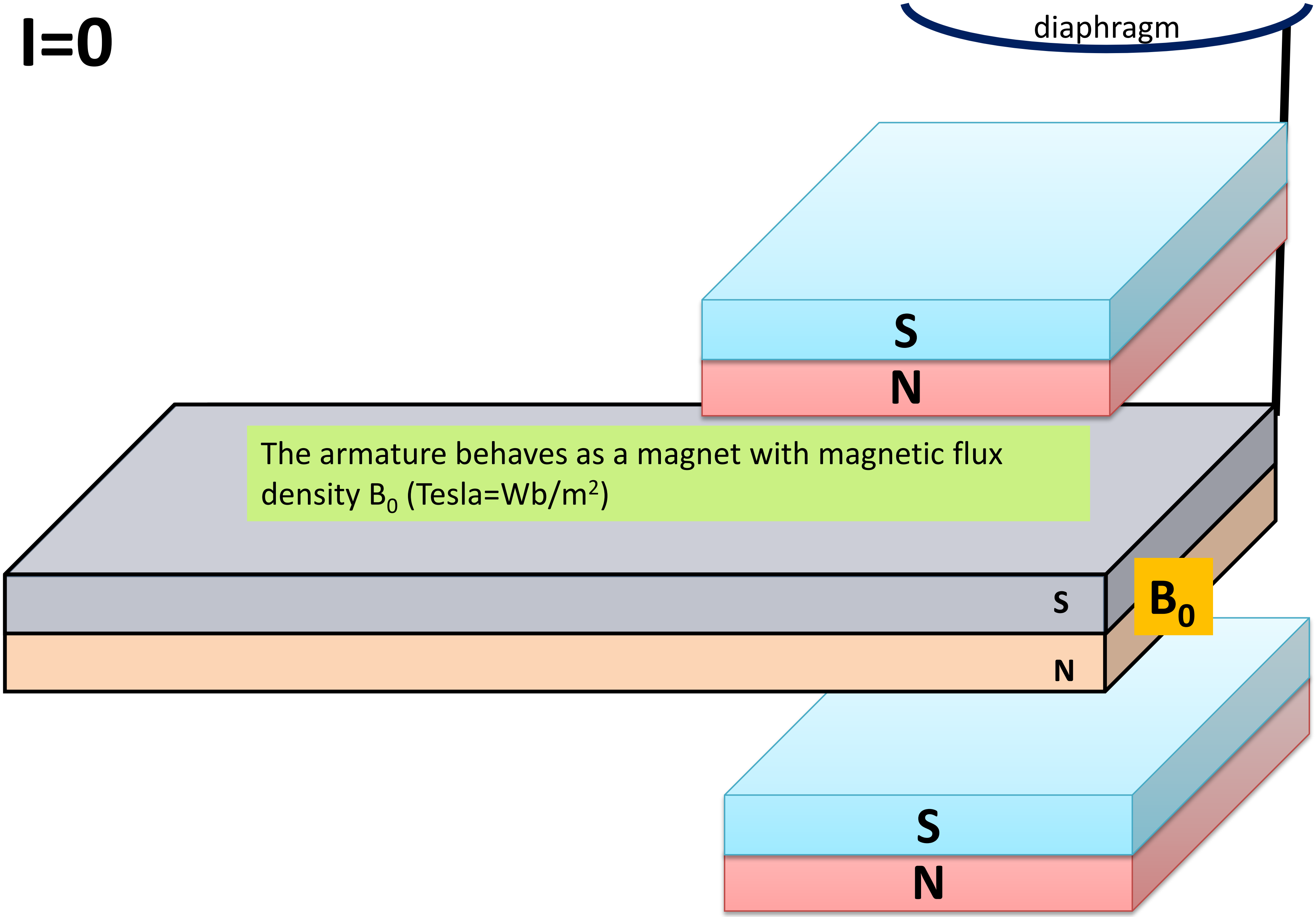
I=0

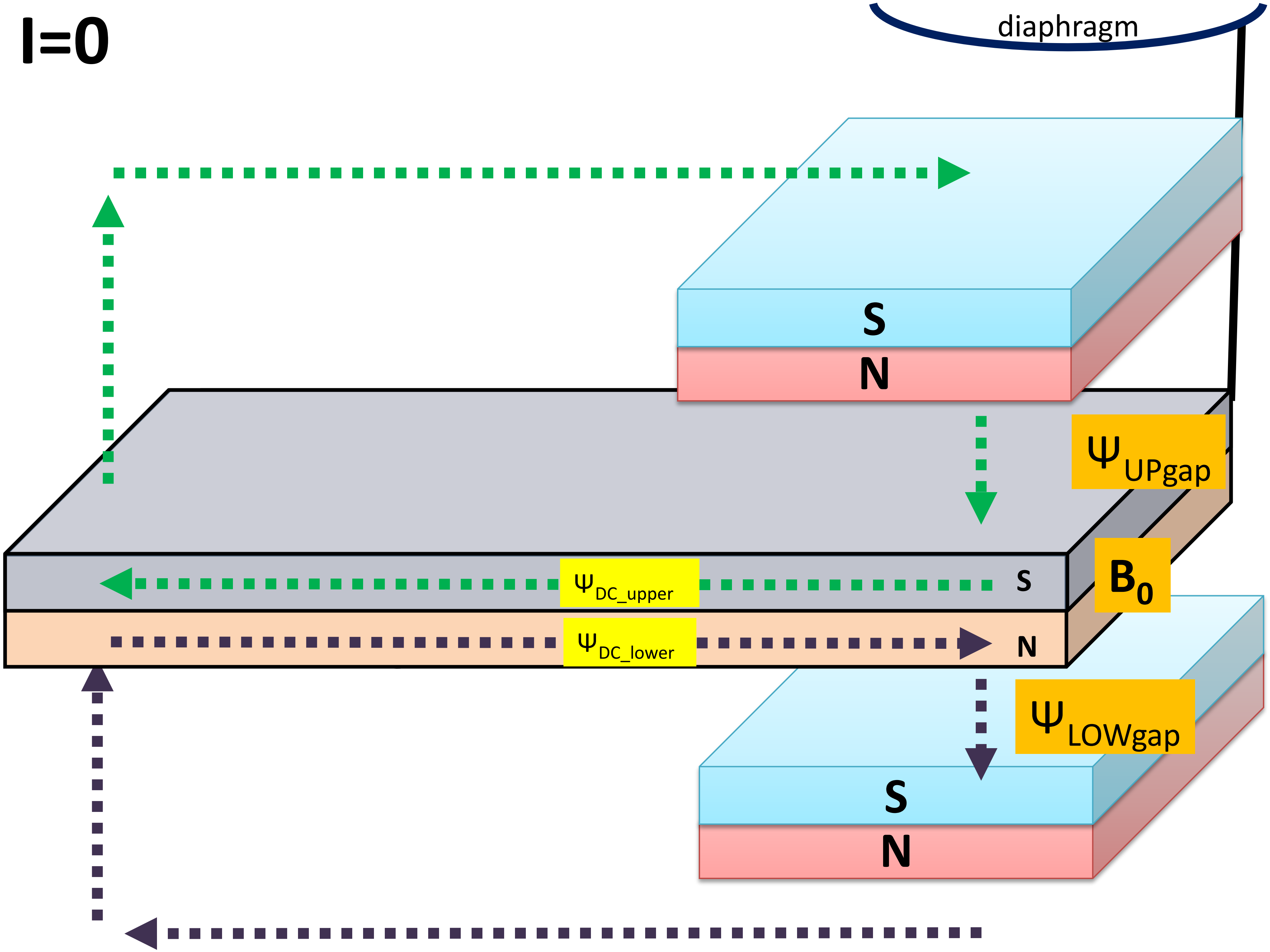

diaphragm
S
N
• Magnetic poles always come in pairs (N and S)
• Polarity of magnetic dipoles, net magnetic density **B**=0
S
N

I=0

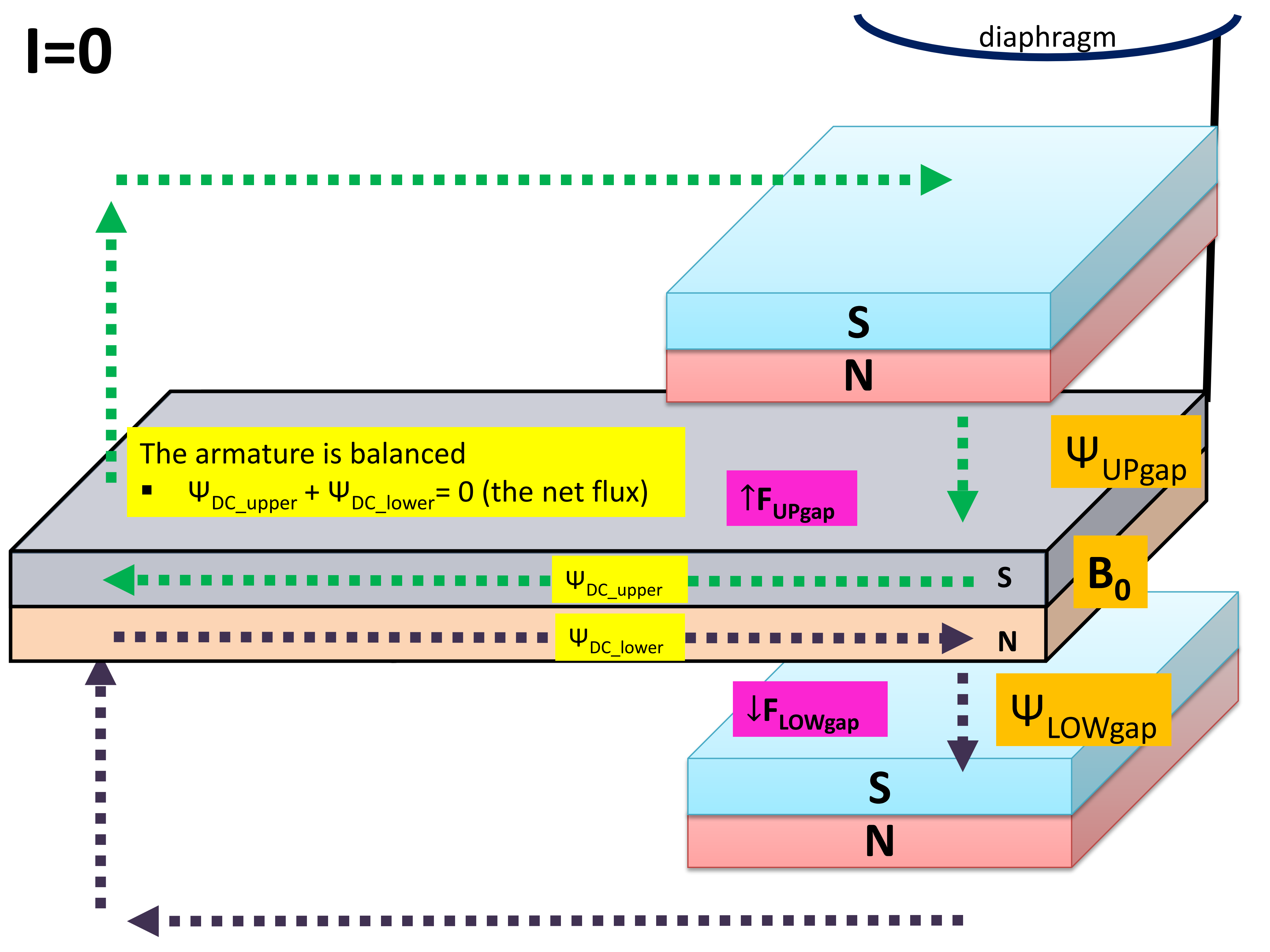


I=0


diaphragm
S
N
The armature behaves as a magnet with magnetic flux density B_0 (Tesla=Wb/m^2)
S
N
B_0
S
N

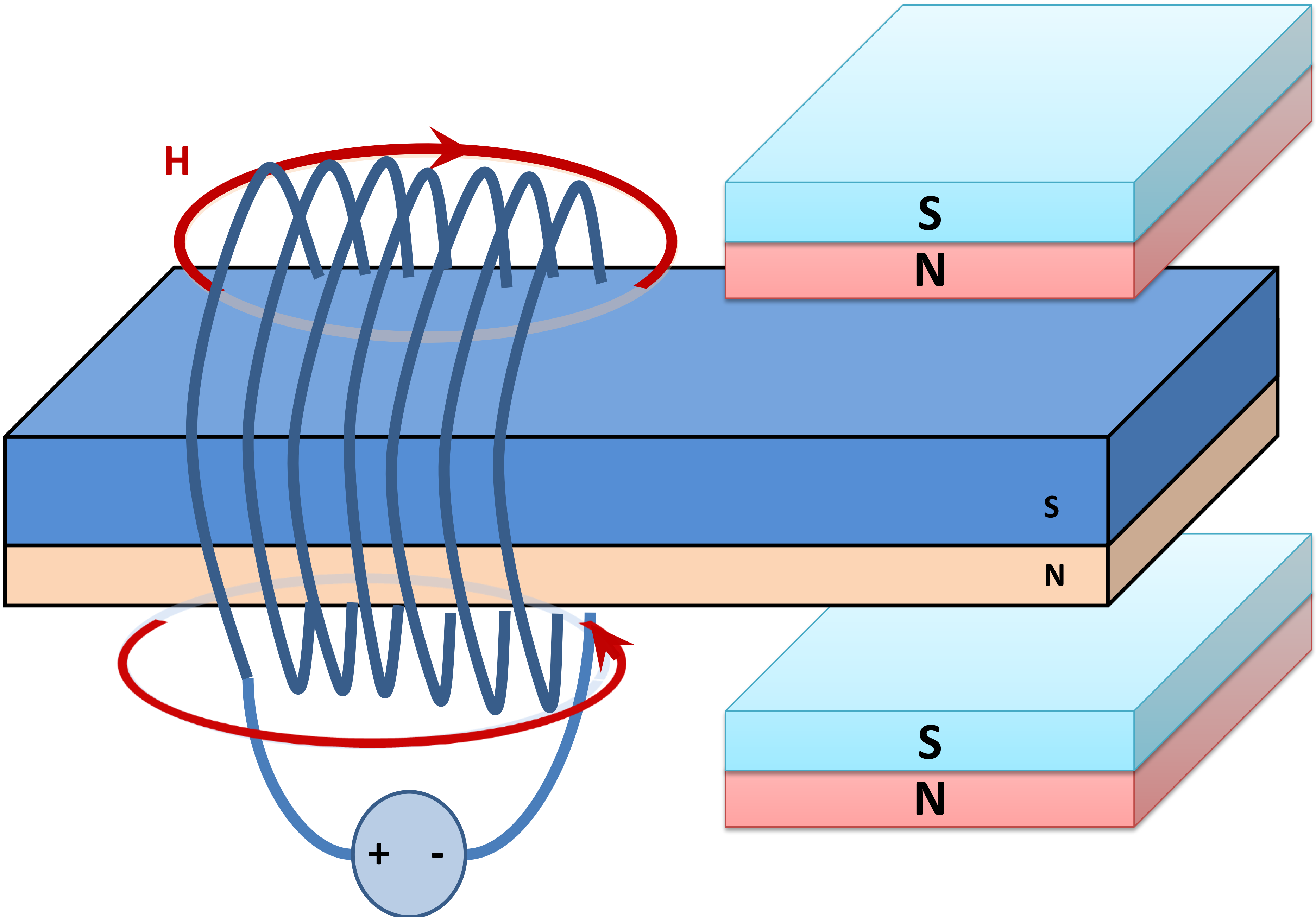


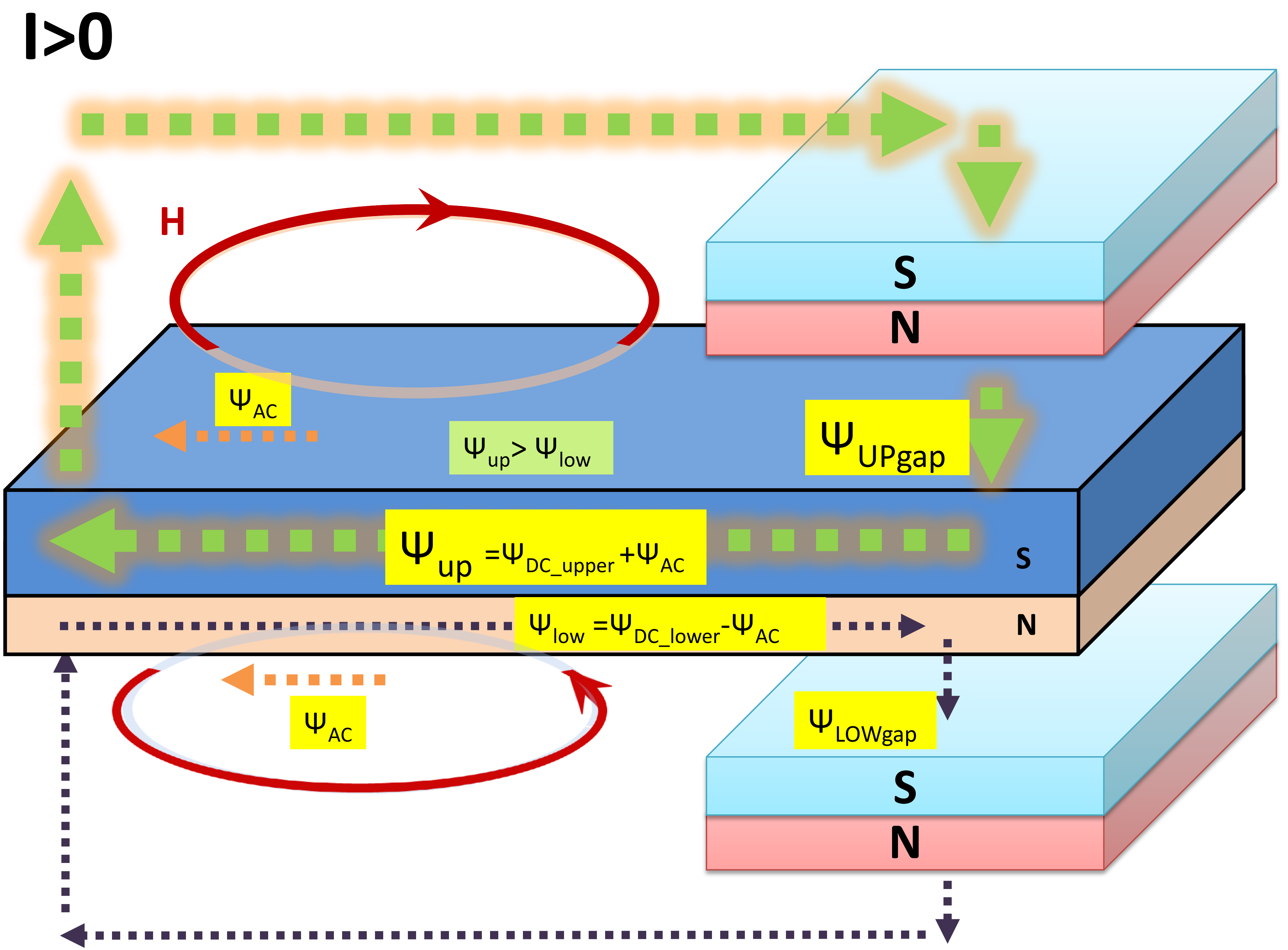
I=0
diaphragm
S
N
Ψ UPgap
S
B0
Ψ DC_upper
Ψ DC_lower
N
Ψ LOWgap
S
N



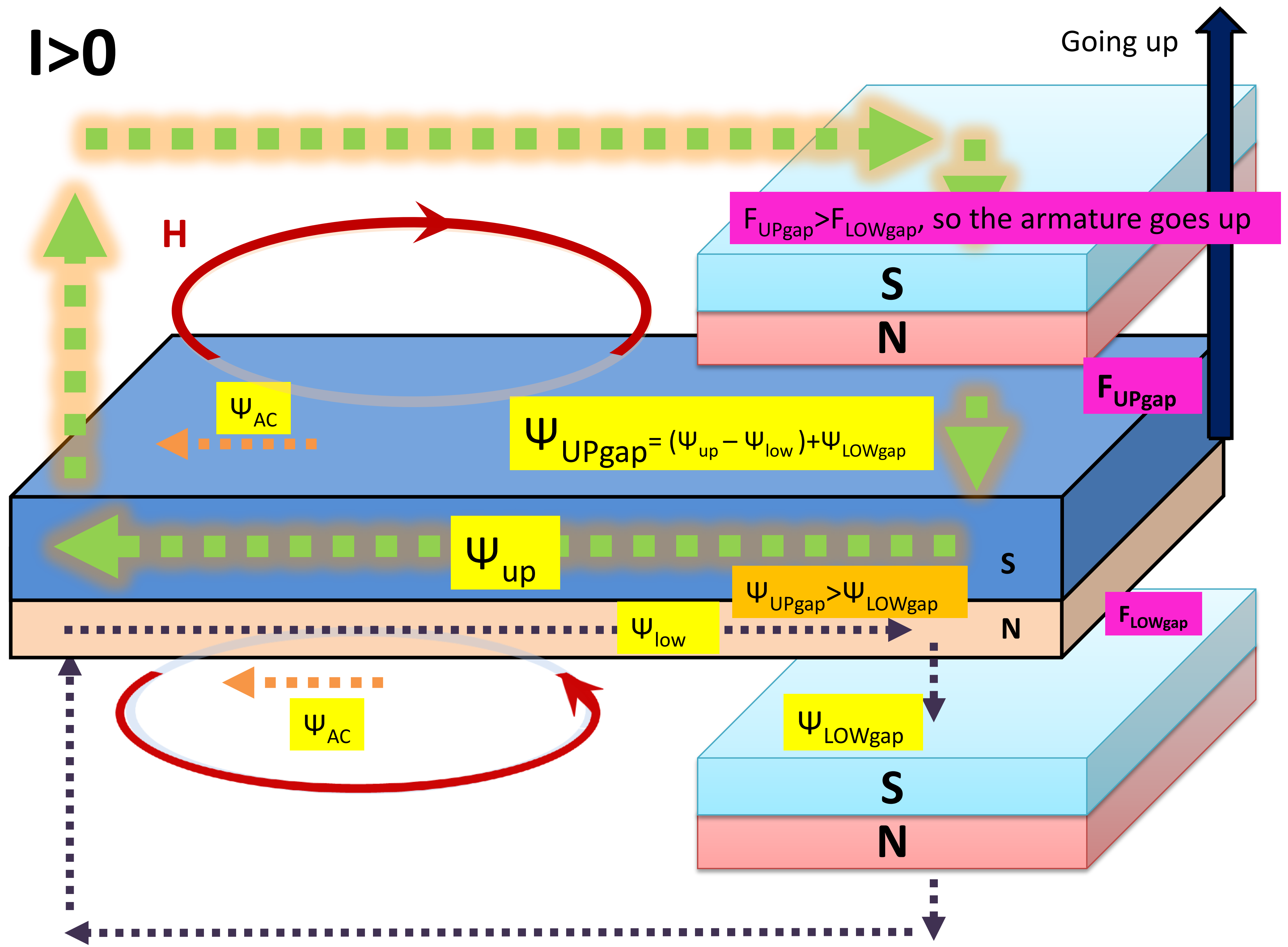
I=0
diaphragm
S
N
The armature is balanced
▪ $\Psi_{DC\_upper} + \Psi_{DC\_lower} = 0$ (the net flux)
↑F_{UPgap}
Ψ_{UPgap}
B_0
S
Ψ_{DC_upper}
Ψ_{DC_lower}
N
↓F_{LOWgap}
Ψ_{LOWgap}
S
N

I>0





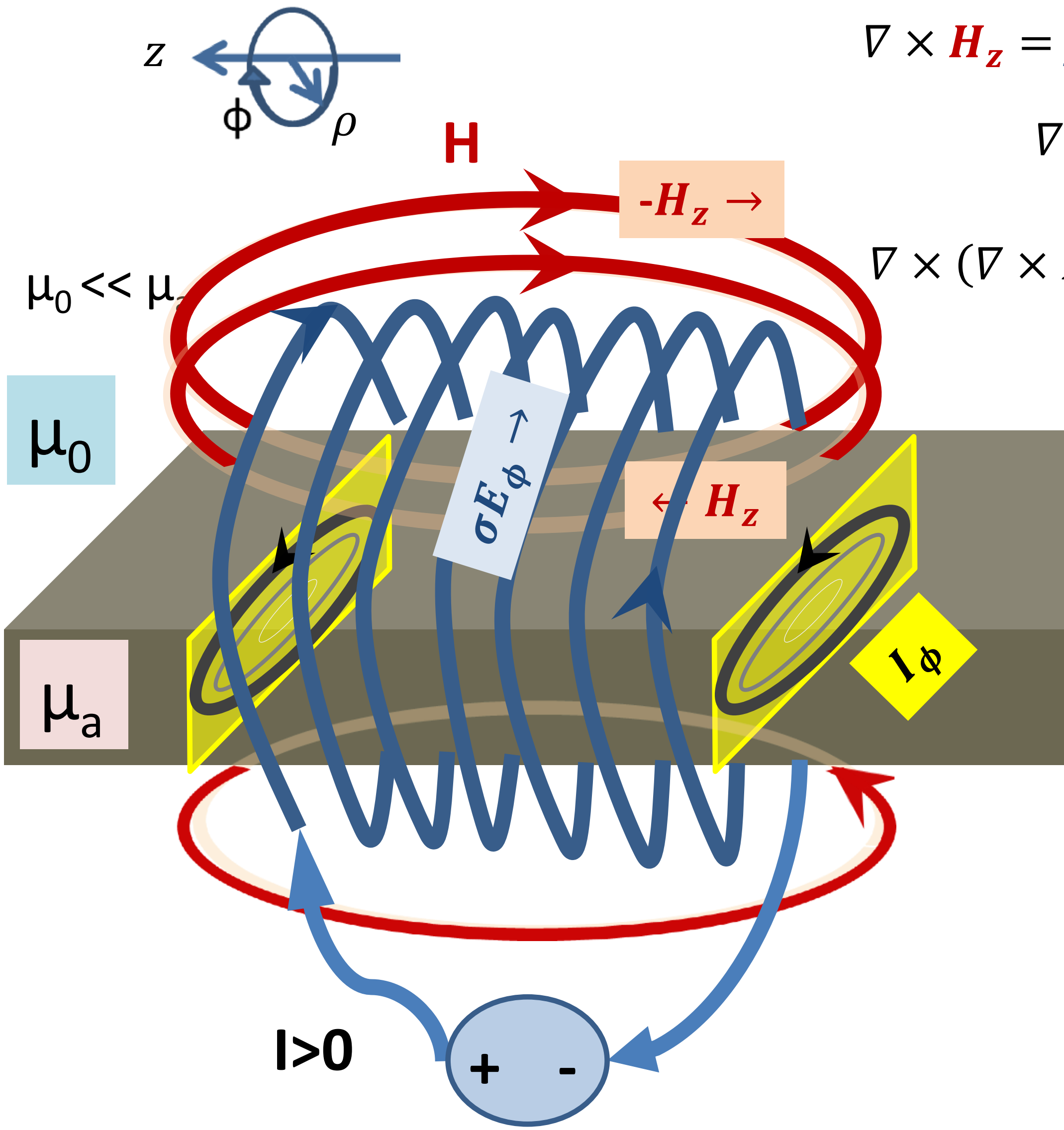
I>0
H
Ψ_AC
Ψ_up> Ψ_low
Ψ_UPgap
S
N
Ψ_up =Ψ_DC_upper +Ψ_AC
S
Ψ_low =Ψ_DC_lower -Ψ_AC
N
Ψ_AC
Ψ_LOWgap
S
N



I>0
Going up
H
$F_{UPgap}>F_{LOWgap}$, so the armature goes up
S
N
Ψ_{AC}
$\Psi_{UPgap}=(\Psi_{up}-\Psi_{low})+\Psi_{LOWgap}$
F_{UPgap}
Ψ_{up}
S
$\Psi_{UPgap}>\Psi_{LOWgap}$
Ψ_{low}
N
F_{LOWgap}
Ψ_{AC}
Ψ_{LOWgap}
S
N

Eddy current

(Vanderkooy 1989)



$$\nabla \times H_z = J_{c\phi} + \dot{D} \approx J_{c\phi} = \sigma E_\phi \text{ (1. Ampere's law)}$$

$$\nabla \times E_\phi = -\dot{B}_z \text{ (2. Faraday's law)}$$

$$\nabla \times (\nabla \times H) = \nabla \underbrace{(\nabla \cdot H)}_{0} - \nabla^2 H \text{ (3. Vector identity)}$$

$$\nabla \times (\nabla \times H_z) = -\nabla^2 H_z (\because 3)$$

$$\nabla \times (\sigma E_\phi) = -\nabla^2 H_z \ (\because 1)$$

$$\sigma \nabla \times E_\phi = -\sigma \dot{B}_z \ (\because 2)$$

Finally, $\nabla^2 H_z = \sigma \mu_a \frac{dH_z}{dt}$

In the frequency domain

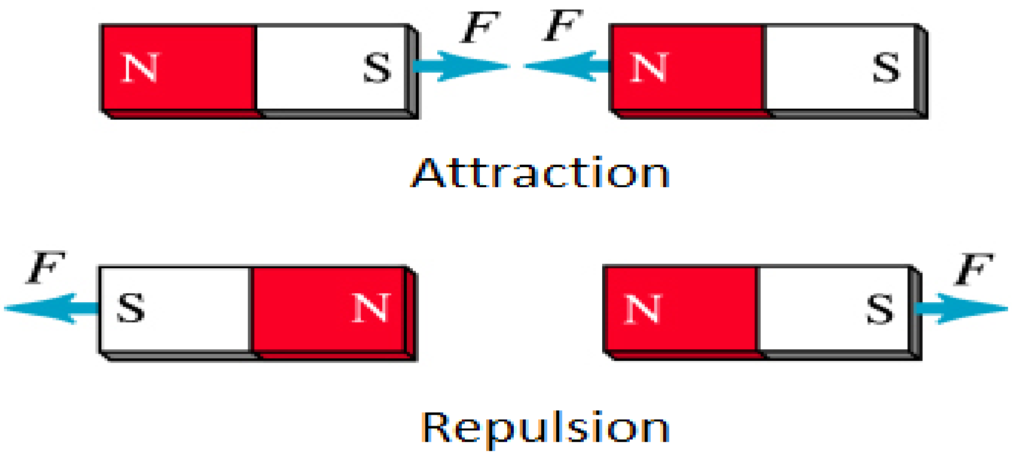
$$(jk)^2 = \sigma \mu_a j\omega$$

$$k_\rho = \pm\sqrt{\sigma \mu_a \omega}\, e^{-\angle 45^\circ} \text{(diffusion)}$$

$$2H_z(\rho, t) = 2H_0 e^{j\omega t - k\rho}$$

Force on the armature and hysteresis

- Force on the armature (F_m) exists for two opposing poles across an air gap
  - Opposite poles attract and like poles repel



- Hysteresis can be explained by describing the F_m,

- Assumption: Core is initially not magnetized
  1. Electrical energy: $W = \int v(t)i(t)dt$ [J =N·m]
  2. $W_d = \int \frac{HlAdB}{lA} = \boldsymbol{\int HdB} = \frac{1}{\mu}\int BdB = \frac{B^2}{2\mu}\ [\frac{J}{m^3} = \frac{N}{m^2}]$

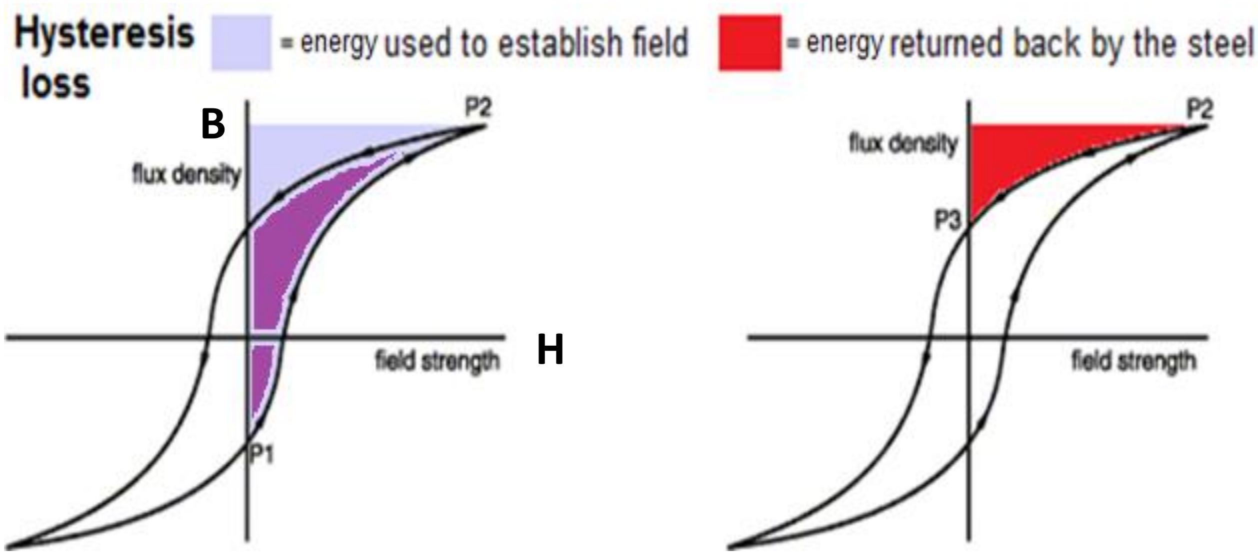
     Faraday: $NA\frac{d}{dt}B$ Ampere: Hl/N
  3. Therefore $F_m = W_d A$

$$F_m = \frac{AB^2}{2\mu} = \frac{A_g {B_g}^2}{2\mu_0} = \frac{{\Psi_g}^2}{2\mu_0 A_g}\ [N]$$

$$W_d = \int \frac{HlAdB}{lA} = \int \boldsymbol{HdB} = \frac{1}{\mu}\int BdB = \frac{B^2}{2\mu}\ [\frac{J}{m^3} = \frac{N}{m^2}]$$

The green formula can be related to the famous hysteresis loop graph

- x-axis and y-axis represent H and B
- Hysteresis loss: subtraction of two regions
- A typical hysteresis phenomenon of Ferro-magnetic material



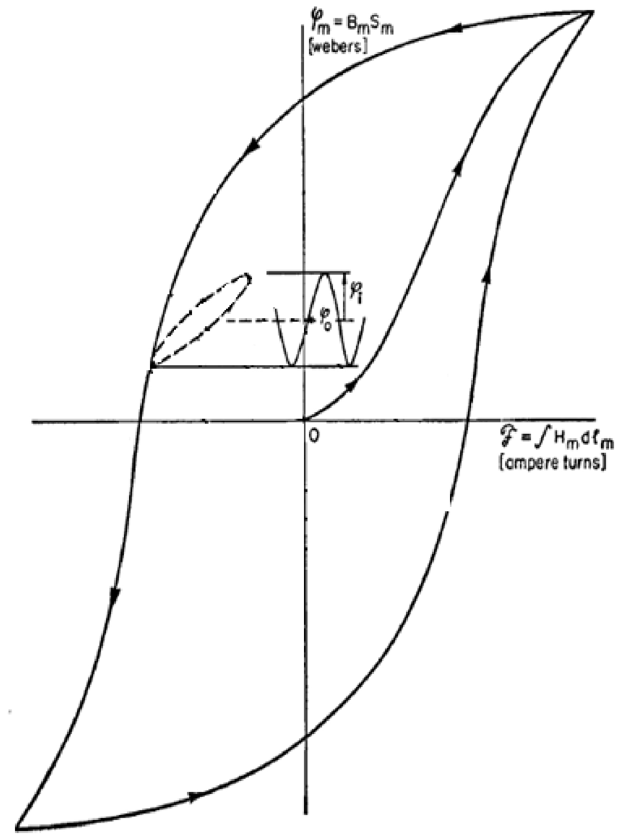
(http://info.ee.surrey.ac.uk/Workshop/advice/coils/power_loss.html#eddy)

We are interested in BAR's operational region

- Hunt 1954, Ch. 7, Moving armature transducer systems
- BAR type receivers are operating in a lens shaped region
  - The region can be linearly approximated
  - Centered at φ_0 (due to the permanent magnet)
  - Alternating φ_i
  - $F_m = \frac{{\Psi_g}^2}{2\mu_0 A_g} = \frac{(\Psi_0+\Psi_i)^2}{2\mu_0 A_g}$

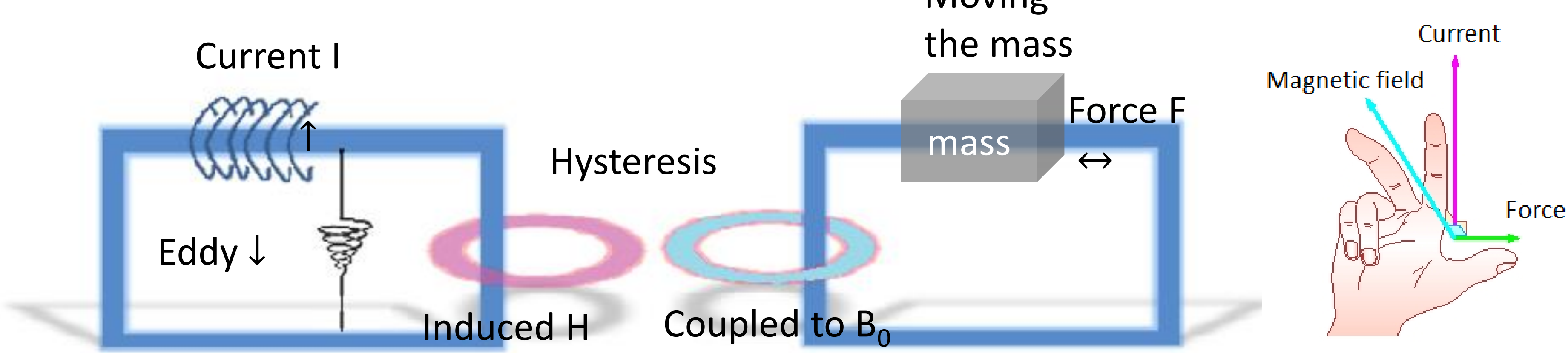
$$= \frac{{\Psi_0}^2+2\Psi_0\Psi_i+\boxed{{\Psi_i}^2}}{2\mu_0 A_g}$$

Non-linear part
Second harmonic distortion



Conclusions

- Principles of the BAR's operation include the Eddy-current effect, hysteresis loss, and force on the two magnets



balanced armature receiver. Hearing Research 301, 156–167

- This work will provide a fundamental, clearer insight into this type of BAR system

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Thanks ☺