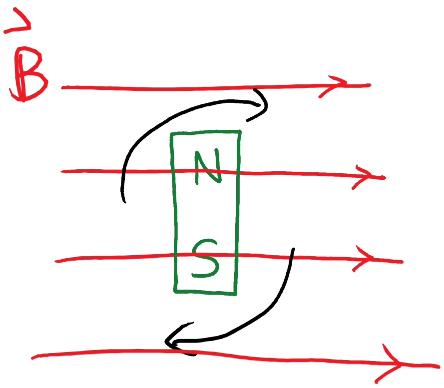
Q: How can we quantify the strength of a magnet?

A1: Stronger magnet feels more torque in constant magnetic field

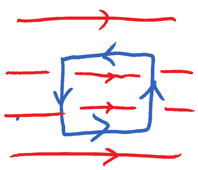
Define MAGNETIC MOMENT $\vec{\mu}$: vector in direction from south pole to north pole



Torque : proportional to B

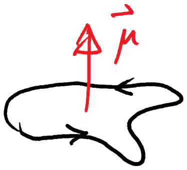
$$\frac{|\tau|}{|B|} = \mu$$ ← constant : larger for stronger magnet.

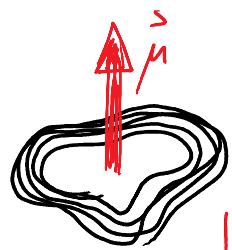
Generally: $\boxed{\vec{\tau} = \vec{\mu} \times \vec{B}}$

e.g. 

$\tau = (I \cdot \text{Area}) \cdot B$ for current loop

$|\vec{\mu}| = I \cdot \text{Area}$ for any planar current loop





N turns:

$|\vec{\mu}| = N \cdot I \cdot \text{Area}$

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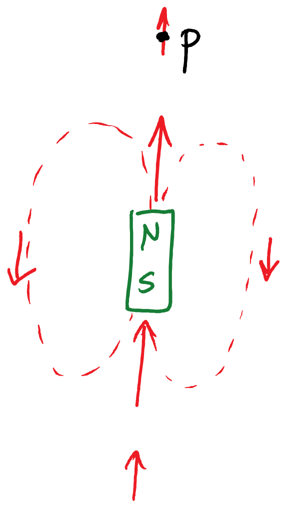
application: electric motor.

A2 (another answer for how to quantify magnet strength):

★ stronger magnet makes stronger field



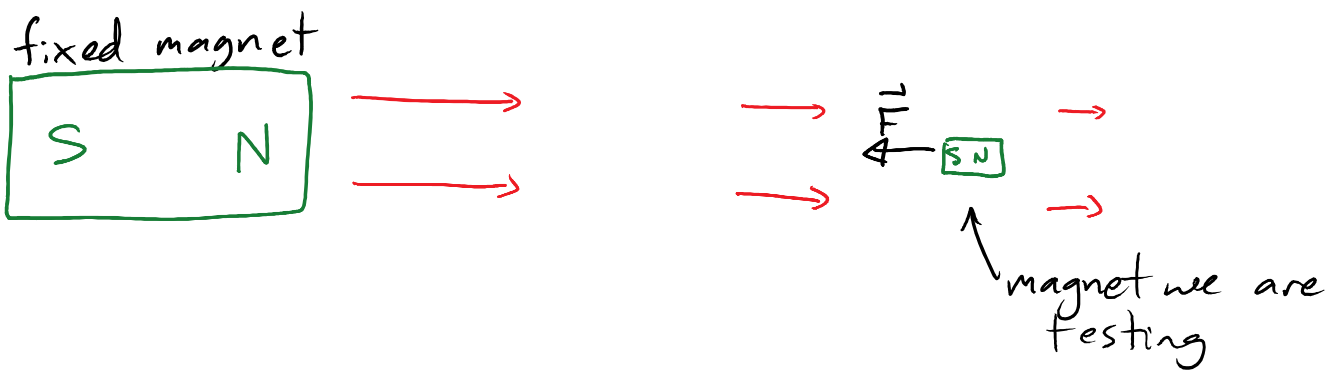
field at point p along axis:

$$B = \frac{\mu_0}{4\pi} \frac{2\mu}{z^3}$$

Larger B for larger μ

assuming $z \gg$ size of magnet

A3: stronger magnet attracted more by other magnet.



Force: arises because field from big magnet is decreasing in magnitude as we move to the right

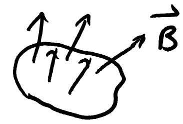
$$|\vec{F}| = |\vec{\mu}| \left| \frac{d\vec{B}}{dx} \right|$$

for setup shown.

more force for larger μ.

clicker: jet

INDUCTION



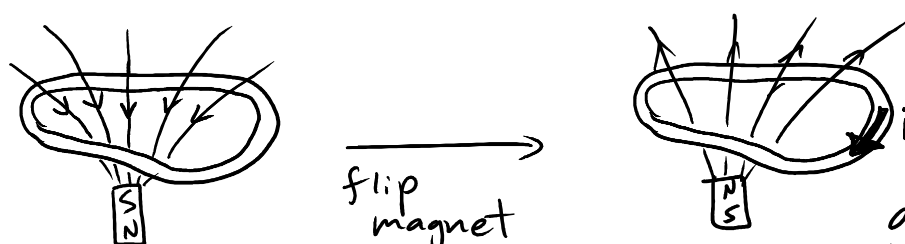
Lenz's Law: $\Phi_M = \int \vec{B} \cdot d\vec{A}$

Changing MAGNETIC FLUX through loop of conductor ⇒ current induced in loop ↓ direction s.t. magnetic field due to current opposes (i.e. partly reverses) change in flux.

Faraday's Law: current due to EMF (electromotive force = "voltage around loop") with magnitude

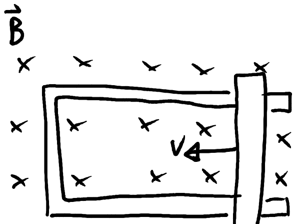
$$\mathcal{E} = \frac{d\Phi_M}{dt}$$

e.g.



induced current: produces downward $\vec{B}$ in loop that partly reverses change

e.g:



flux (into picture) decreasing

∴ induce current to produce more flux into picture i.e. Clockwise current.

WHY? changing flux ⇒ $\vec{B}$ changing OR loop changing

Induced current due to 2 DIFFERENT physical effects for these 2 cases.

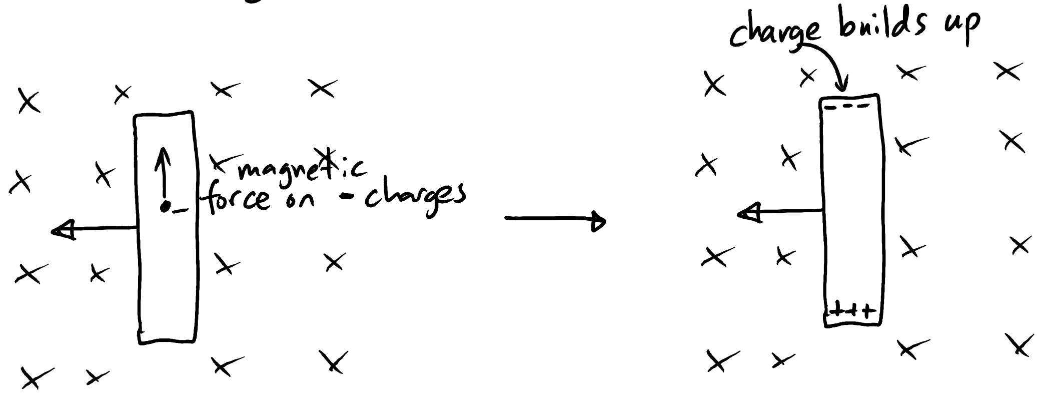
Case 1: changing loop

⇓

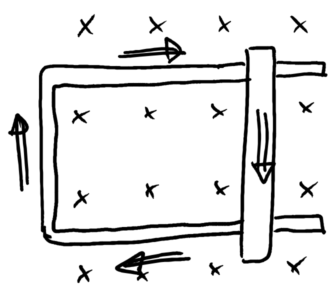
conductor moving through $\vec{B}$ field

⇓

charges in conductor feel force

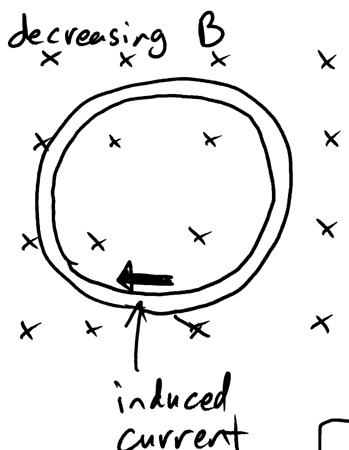


potential difference between ends: like battery



this "motional EMF" causes current to flow if connected to complete loop

Case 2: changing field



- loop fixed
- charges in loop not moving
- no magnetic forces
- induced current must be due to ELECTRIC FIELD

Conclusion:

changing magnetic fields $\xrightarrow{\text{produce}}$ electric fields

New law of physics!