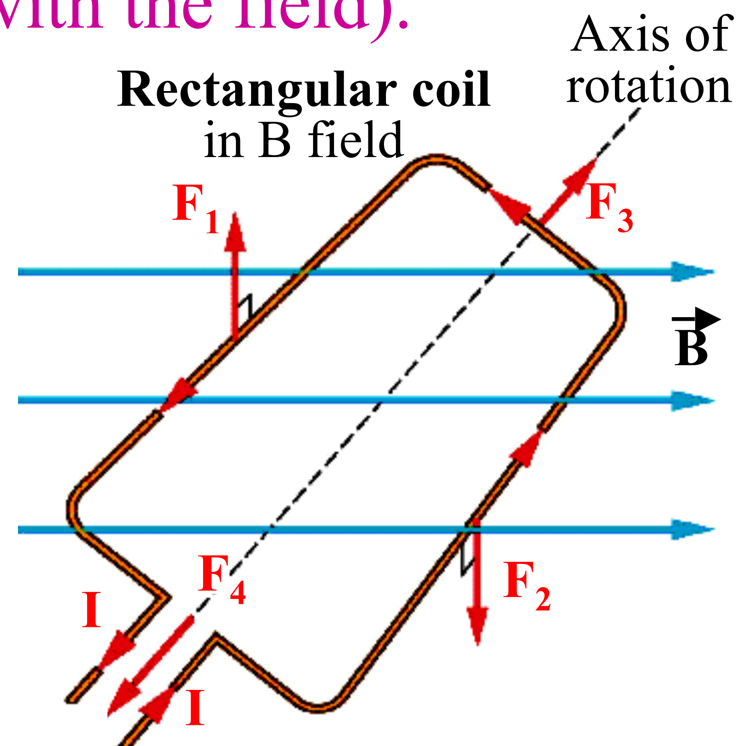
Recap: Electric Motor

- If we place a **current loop** in an **external magnetic field**, it will experience a **torque**.
- This **torque** is the **same force** a **bar magnet** would **experience** (if not initially aligned with the field).
- Using **Right Hand rule** the forces ($F = B. I. l$) create:
  - · F_1 and F_2 combine to produce a **torque.**
  - · F_4 and F_3 produce **no torque** about the **axis of rotation**.

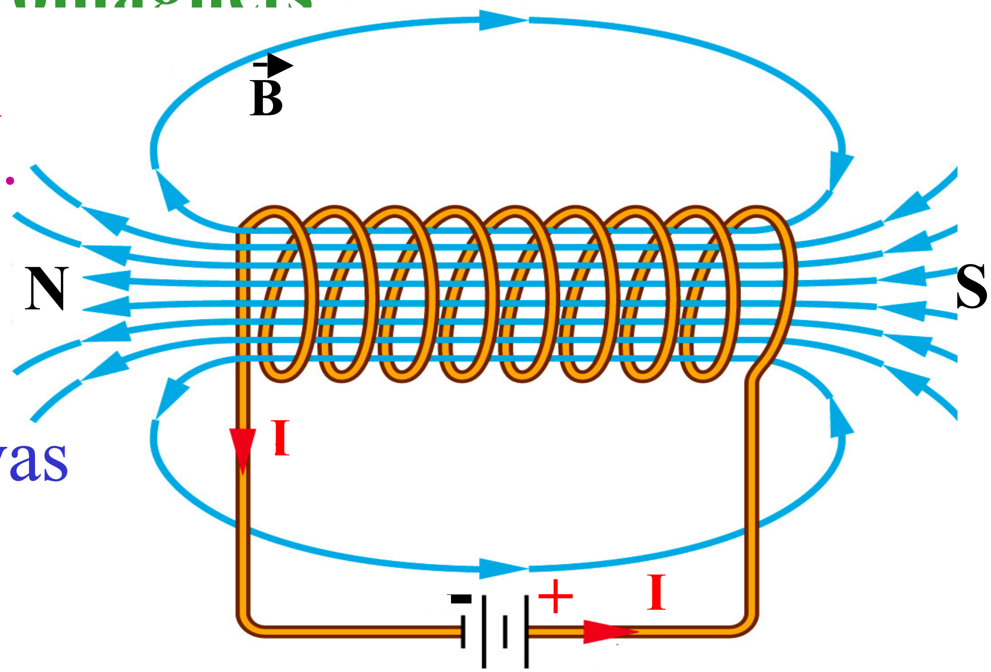


- Forces F_1 and F_2 will rotate loop until it is perpendicular to magnetic field (i.e. vertical in figure).
- To keep **coil turning** in an **electric motor** must **reverse current** direction **every ½ cycle**.
- **AC current** is **well suited** for operating electric motors.
- In a DC motor need to use a "split ring" or "**commutator**" to reverse current.

- **Electric motors** (AC and DC) are very common:
  Magnitude of torque is proportional to **current** flowing.
  Uses: car starter motor; vacuum cleaners; current meters
- **AC motors** run at a **fixed speed**.
- **DC motors** have **adjustable speed** (depending on applied voltage.

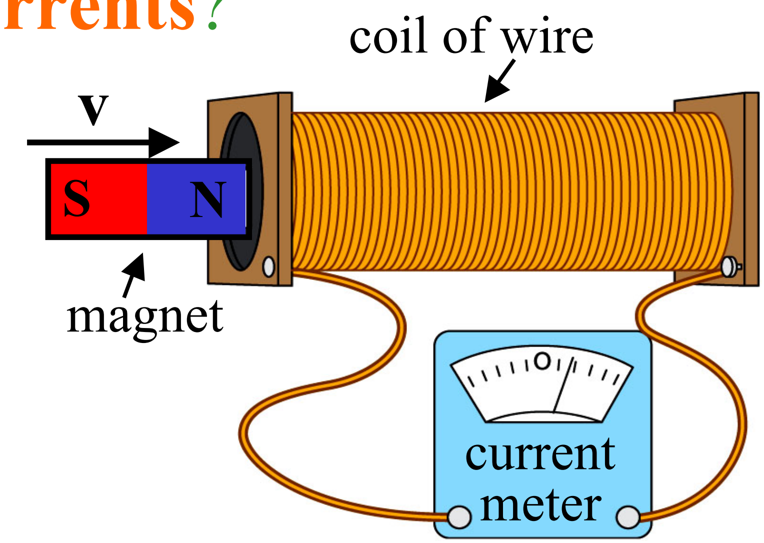
Electromagnets

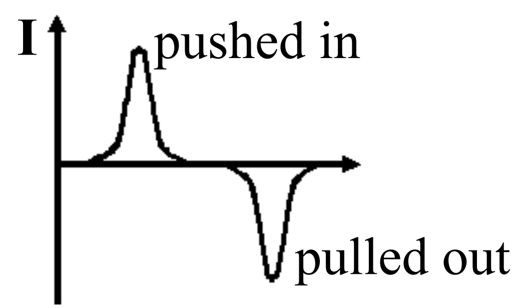
- If we take a **single loop** and **extend** it into a **coil of wire** we can create a **powerful electromagnets**
- **Magnetic field** proportional to **number of turns** on coil.
- If add iron/steel core field **strength enhanced**.
- Ampere suggested source of magnetism in materials was current loops – **alignments** of "**atomic loops**" gives a **permanent magnet**.



Electromagnetic Induction

- An **electric current** produces a **magnetic field** **but** can **magnetic field** produce **electric currents**?
- Magnet moved in and out of wire coil.
- **Michael Faraday** (U.K.) discovered that when **magnet** is **moved** in /out of a core a **current** was **briefly induced**.
- **Direction** of current **depended** on **direction** (in/ out) of magnet.
- When **magnet stationary** **no current** is **induced**.



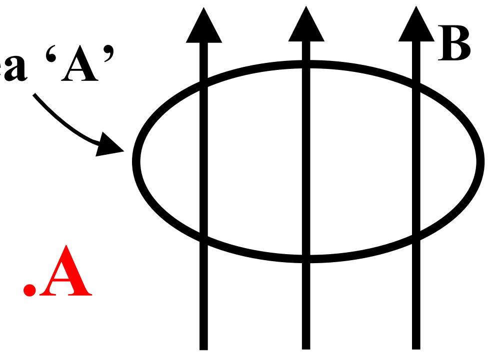


- **Strength** of **deflection** depended on **number of turns** on coil and on **rate of motion** of the magnet.

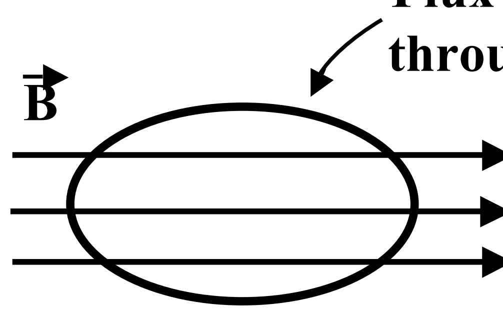
Result: **Current induced** in coil when **magnetic field** passing through coil **changes**.

Magnetic Flux

- Number of **magnetic field lines** passing through a **given area** (usually area of loop).



$\Phi = B\,.A$



$\Phi = 0$

Maximum flux is obtained when **field lines** pass through circuit **perpendicular** to coil.

If **field lines parallel** to circuit plane, the **flux = 0** as **no field lines** pass **through coil**.

❖ **Faraday's Law: A voltage is induced in a circuit when there is a changing magnetic flux in circuit.**

$$\varepsilon = \frac{\Delta\Phi}{t}$$ (electromagnetic induction)

- **Induced voltage 'ε' equals rate of change of flux.**

- $\Delta\Phi$ is **change** in flux
- The **more rapidly** the flux changes, the larger the induced voltage (i.e. larger meter swing).
- As magnetic **flux passes** through **each loop** in coil the total flux,

$$\boldsymbol{\Phi = N \, .B \, .A}$$

- Thus the **more turns** of wire, the **larger** the **induced voltage**.

Example: Determine induced voltage in a coil of 100 turns and coil area of 0.05 m^2, when a flux of 0.5 T (passing through coil) is reduced to zero in 0.25 sec.

$$\Phi = N \, .B \, .A = 100 \times 0.5 \times 0.05$$

$$\Phi = 2.5 \; T \, .m^2$$

N = 100 turns
B = 0.5 T
A = 0.05 m2
T = 0.2 s

Induced voltage:

$$\varepsilon = \frac{\Delta\Phi}{t} = \frac{2.5 - 0}{0.25} = 10 \text{ v}$$

• **Question**: What is the direction of induced current?

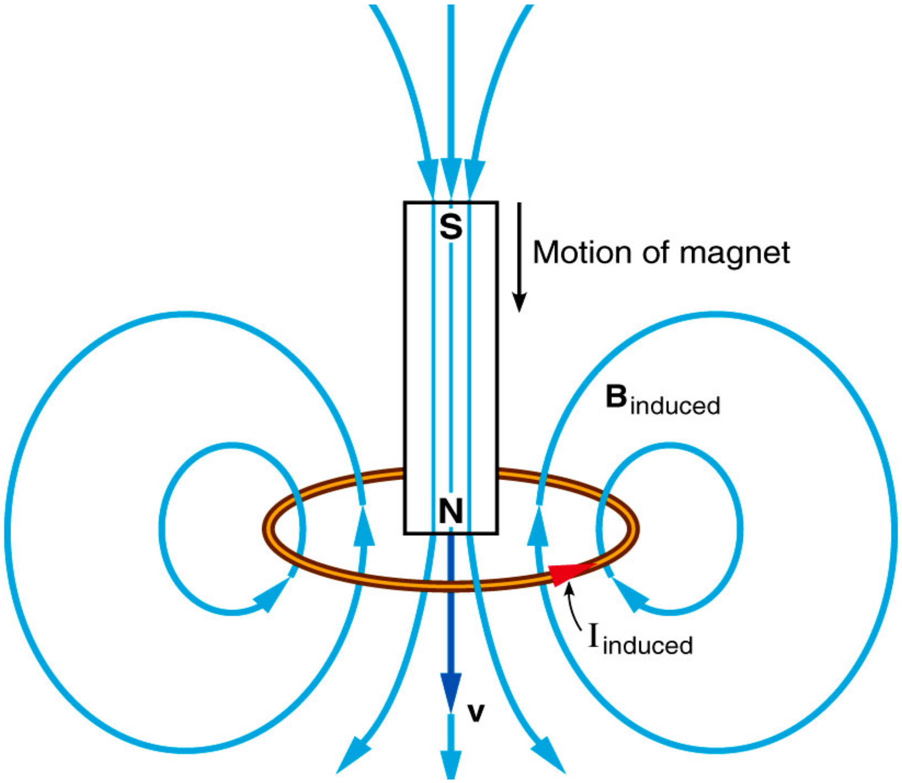
Lenz's Law (19th century):

❖ **The direction of the induced current (generated by changing magnetic flux) is such that it produces a magnetic field that *opposes* the changes in original flux.**

E.g. If **field increases** with time the field produced by **induced current** will be **opposite in direction** to original external field (and vice versa).

• As magnet is pushed through coil loop, the **induced field opposes** its field.

Note: This also explains why the **current** meter needle **deflects** in **opposite directions** when magnet pulled **in** and **out** of **coil** in laboratory demonstration.



Waves **(Chapter 15)**

Waves are **everywhere:**

- atmosphere (acoustic) - oceans (tides)
- land (seismic) - space (radiation)

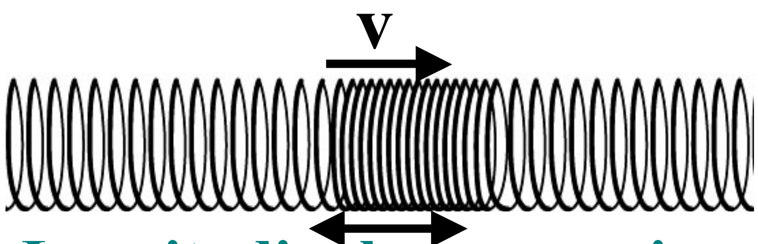
- Waves are **very important mechanism** for the **transport** of **energy**.
- Wave motions have implications in **all** areas of physics: an enormous range of phenomena can be explained in terms of waves, from quantum mechanics to tsunamis!

So what is a wave?

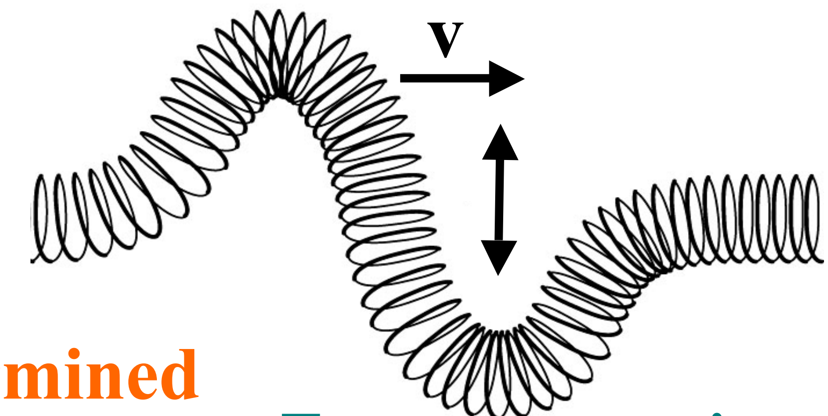
Fundamental question: As waves **move** towards the **shore**, why is there **no buildup** of **water** on the beach?

- **Result:** A wave is a **disturbance** that **moves** within a **medium**. (but the medium itself **stays put**!)
- A wave can consist of a **single "pulse"** or a **series** of **periodic pulses**.

- The **wave disturbance** can be in the form of a:



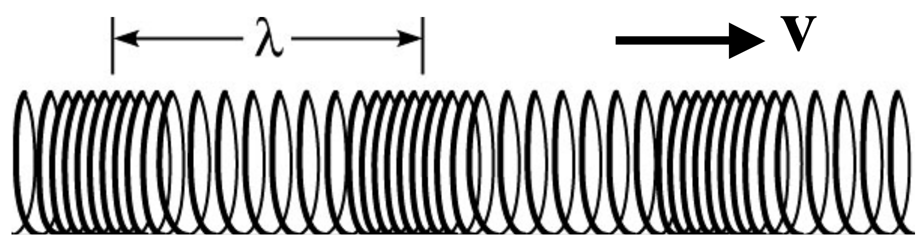
Longitudinal compression



Transverse motion

- **Velocity** of the ‘pulse’ is **determined** by the **medium** it is propagating in.
- The **wave acts** to **transmit energy** through the **medium**… (shore line erosion).

Periodic waves:



- A periodic wave consists of a **series** of **pulses** at **regular** (equal) **time intervals**.
- Time between the pulses is called the wave period (T).
- **Frequency** of wave is **number of pulses per second**:

$$f = \frac{1}{T} \quad \text{(Units Hertz, Hz)}$$

- **Separation** of the **pulses** is called the **wavelength** (**λ**).
- Thus for a **periodic disturbance**, the **velocity** is **equal** to **one wavelength** (i.e. distance between two successful pulses) **divided** by **one period** (i.e. time between the pulses).

$$v = \frac{\lambda}{T} \quad \text{or} \quad v = \lambda . f$$

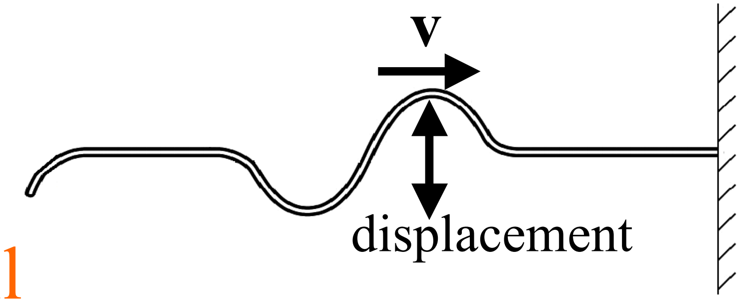
- This is valid for **any periodic wave** (sound, light, etc) and relates the **velocity** to **wavelength** and **frequency**.
- The wave **velocity depends** on the properties of the **medium** (e.g. air, water, ground) and is often known.
- The **wave frequency** is a **property** of the **wave source** (e.g. speech).
- As the **frequency varies**, the **wavelength changes:**

$$v = \lambda . f$$

… to keep **velocity constant**.

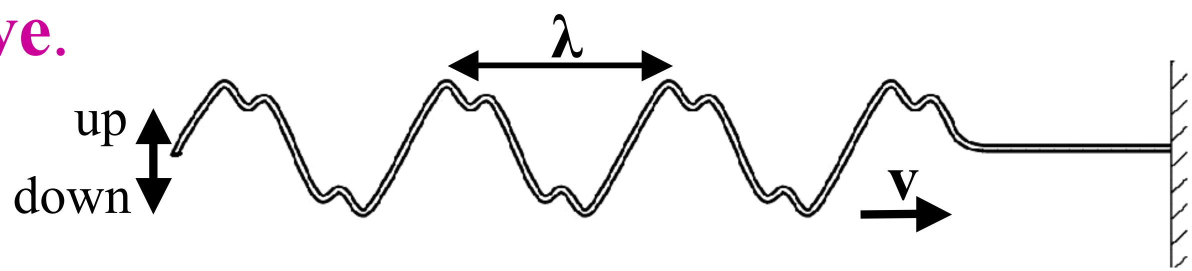
Example: Waves on a Rope

- By moving **free end up** and **down** we can generate a **transverse** wave '**pulse**'.



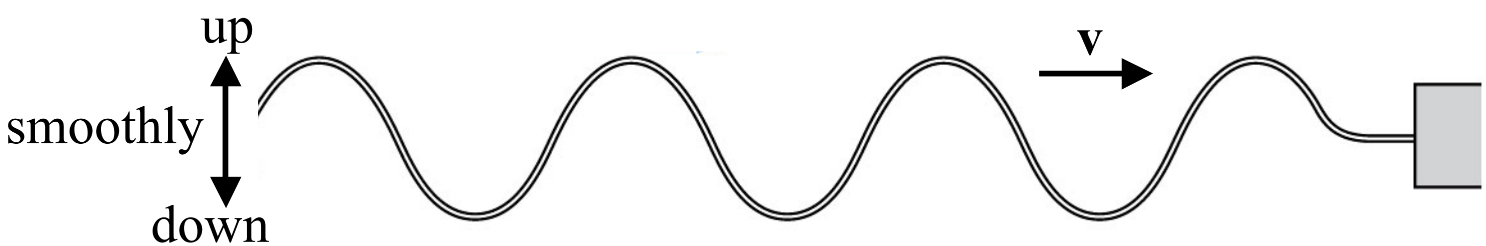
Pulse **propagates** down rope to wall **creating** an **instantaneous vertical displacement**.

- A series of '**snap-shots**' would show the **wave moving** down rope at **constant speed** 'v'.
- If we **repeat** up /down motion **regularly** you can make a **periodic wave**.



- A **periodic wave** can have a **complex shape** depending on the **perturbation induced**.
- When the **wave reaches** the **wall,** it is **reflected back** along rope and then **interferes** with the **forward** moving **wave** creating a **more complex** wave **pattern**.

Simple Harmonic Wave (Pure Sinusoid)

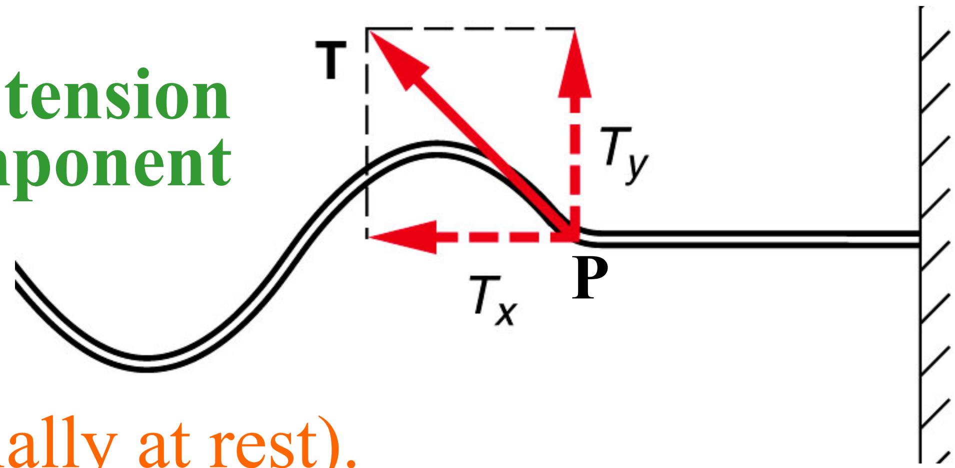


- When we move rope end up and down very **smoothly** and **regularly**, we create a **sinusoidal variation** called a "**harmonic wave**".
- **Harmonic waves** are **easy to create** as the individual "**elements**" in a **rope** act like a **spring** which is a **natural harmonic oscillator** (Force α – displacement).
- **Harmonic waves** are very **important** for **everyday wave analysis** as any **complex periodic** wave **motion** can be **broken down** into a **sum** of pure **harmonic waves**.
- **Fourier analysis** – uses harmonic waves as building blocks for complex everyday wave motions (e.g. speech).

Why does the pulse move?

- Experiments show **velocity** is **independent** of wave **shape**.

- **Lifting** the rope causes the **tension** in it to gain an **upward component** of motion.



- This **upward force** acts on **element** of rope to **right** of point 'P' (which was initially at rest).
- This causes the **next element** to **accelerate upwards** and so on down the rope.
- **Velocity of pulse** (wave) depends on how **fast** the **individual elements respond** to the initial **perturbation** (i.e. on how fast they can be **accelerated** by the **tension force**).

$$v = \sqrt{\frac{T}{\mu}} \qquad \text{where } \mu = \frac{\text{mass of rope}}{\text{length}}$$

Result (for a rope):

- **Larger tension** => **higher** wave **velocity.**
- **Heavier rope** (μ larger) => **slower** wave **speed**.

Example: A rope of length 12 m and total mass 1.2 kg has a tension of 90 N. An oscillation of 5 Hz is induced. Determine velocity of wave and wavelength.

L = 12 m
m = 1.2 kg
T = 90 N

1) First we need to calculate μ:

$$\mu = \frac{m}{L} = \frac{1.2}{12} = 0.1\,\text{kg/m}$$

2) now velocity:

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{90}{0.1}} = \sqrt{900} = 30\ \text{m/s}$$

3) and wavelength:

$$v = f.\lambda \quad \text{or} \quad \lambda = \frac{v}{f}$$

$$\lambda = \frac{30}{5} = 6\ \text{m}$$