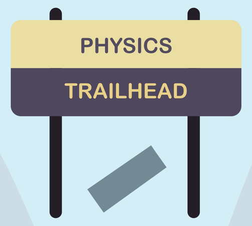
Physics of Magnetism

The essentials

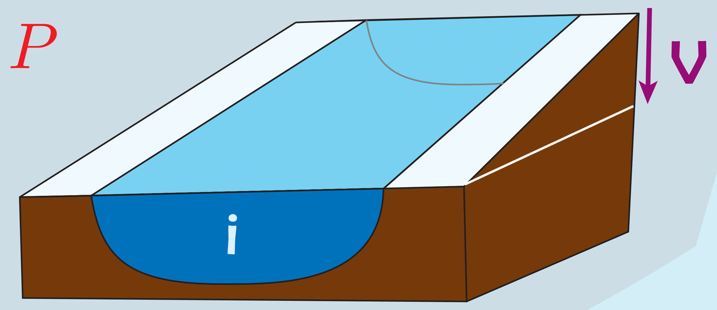


James Maxwell

Potential (V), current (i) and power (P)

Maxwell's equations are the foundation for classical electromagnetism. Electric potential (V) and current (i) together generate power (P). This is analogous to a flowing river, in which the fall of the river (potential) and the amount of water per time (current) together dictate the power that could be used to drive a mill wheel.

$$Vi = P$$

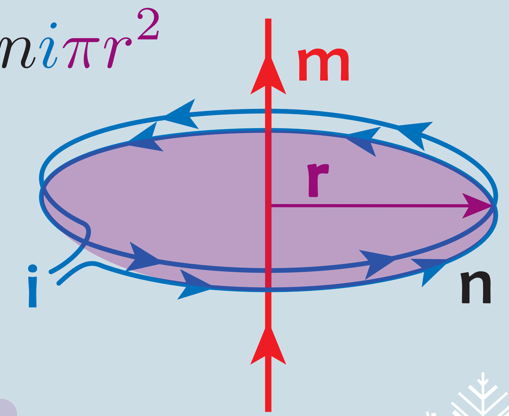


Potential (V): Volt (V)
Current (i): Ampere (A)
Power (P): Watt (W)

Magnetic moment (m)

$$m = ni\pi r^2$$

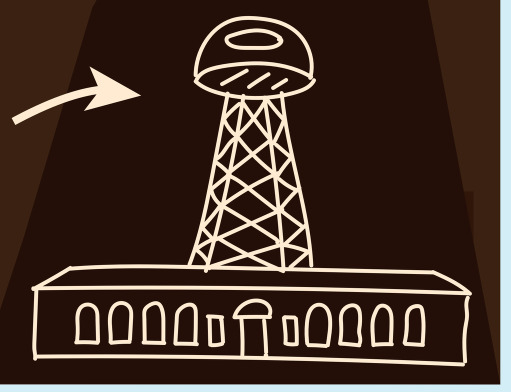
A magnetic moment (m) is generated by a current (i) in a bent wire following the right-hand rule. The strength of m is proportional to the strength of i, the loop area ($\pi \times r^2$), and the number of windings (n).



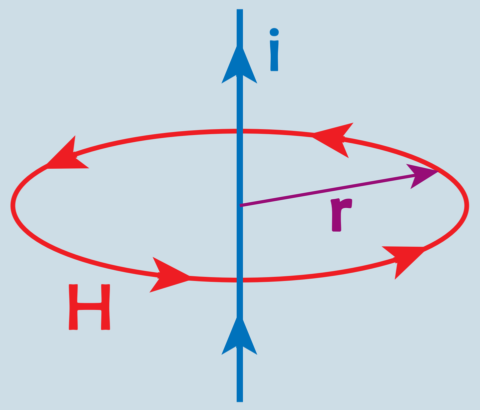
Number of windings (n): dimensionless (-)
Current (i): Ampere (A)
Radius (r): meter (m)
Magnetic moment (m): Ampere meter-squared (Am^2)

Nikola Tesla

Nikola Tesla invented the alternating current (AC) and also pioneered with wireless transmission of power. The unit of magnetic induction is named after him.



Magnetic field (H)



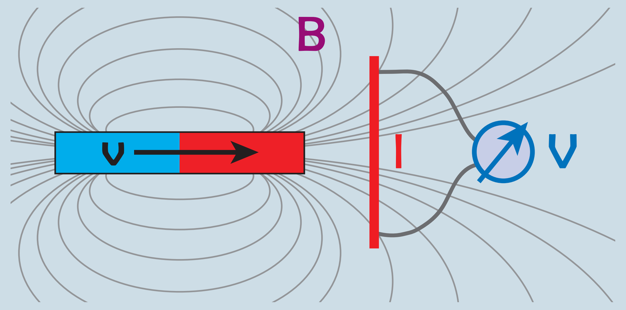
A magnetic field (H) is generated by a current (i) in a wire following the right-hand rule. The strength of H is proportional to the strength of i over the distance to the wire (r) times 2π. This formula is known as Ampère's Law.

$$H = \frac{i}{2\pi r}$$

Current (i): Ampere (A)
Radius (r): meter (m)
Magnetic field (H): Ampere per m (A/m)

Magnetic induction (B)

Magnetic induction (B) is a measure of the density of the flux lines. A magnet moving at velocity (v) induces a potential (V) in a wire with length (l) that is proportional to the density of the fluxlines intersecting the wire.



$$V = vlB$$

Potential (V): Volt (V)
Velocity (v): meter per second (m/s)
Length (l): meter (m)
Magnetic induction (B): Tesla (T) = Vs/m^2

Remanent magnetization (M/Ω)

The magnetization of a permanent magnet is its normalized magnetic moment. A magnet's moment can be normalized to its volume (M) or its mass (Ω).

Magnetic moment (m): Ampere meter squared (Am^2)
Volumetric magnetization (M): Ampere per meter (A/m)
Mass normalized magnetization (Ω): Ampere meter squared per kilogram (Am^2/kg)

Induced magnetization (M_i)

Applying a magnetic field (H) to a material may give rise to an induced magnetization (M_i). The strength of M_i is equal to the bulk susceptibility (χ_b) of the material times H.

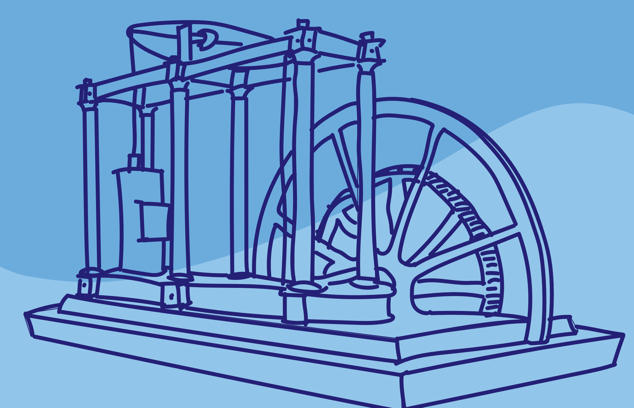
$$M_i = \chi_b H$$

Induced magnetization (M_i): Ampere per meter (A/m)
Magnetic field (H): Ampere per meter (A/m)
Bulk susceptibility (χ_b): dimensionless (-)

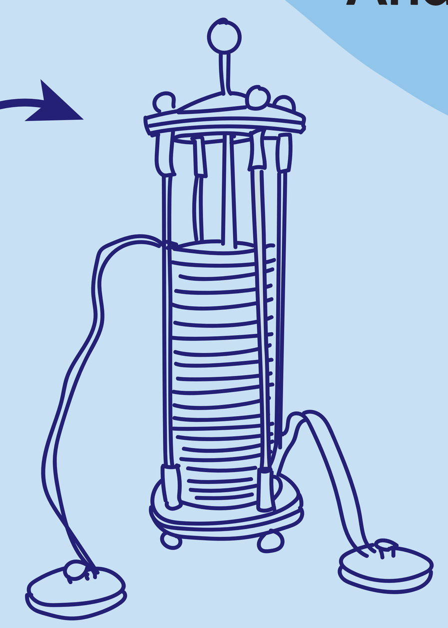
Alessandro Volta

André-Marie Ampère invented the solenoid and the electrical telegraph. The unit of electric potential is named after him.

André-Marie Ampère



Alessandro Volta invented the 'Voltaic pile', the first battery, in 1799. The unit of electric potential, Volt, is named after him.



James Watt invented the steam engine in 1776 which drove the industrial revolution. The unit of power is named after him.

James Watt

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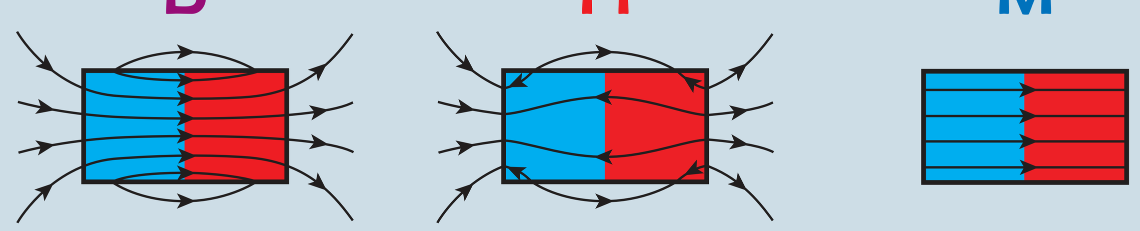
B versus H versus M

The magnetic induction (B) is given by the sum of the magnetic field (H) and the magnetization (M) times the permeability (μ) of the medium. The permeability of air and most Earth materials is close to the permeability of free space. Outside a magnetized body M = 0, and B and H are then simply related through the permeability of free space ($\mu_0 = 4\pi \times 10^{-7}$ H/m).



$$B = \mu_0(H + M)$$

Magnetic induction (B): Tesla (T)
Magnetic field (H): Ampere per meter (A/m)
Magnetization (M): Ampere per meter (A/m)
Permeability (μ_0): Henries per meter (H/m)