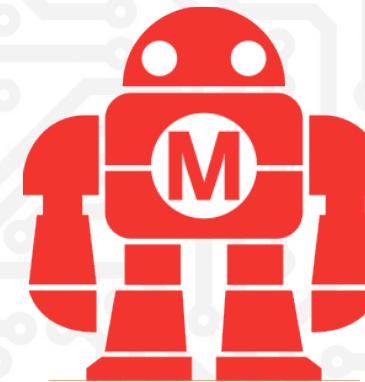


Making Makers



Robot Garden

Course Outline

- Introductory Electronics
- Arduino Programming
- Actuators
 - Motors, Solenoids
 - Shape Memory Alloy
- Sensors
 - Piezoelectric
 - Capacitive



Units

Distance – meters (m)

Mass – kilograms (kg)

Time – seconds (s)

Charge – Coulomb (C)

Current – Amp (A)

Resistance – Ohm (Ω)

Magnetic Field – Tesla (T)

f – femto (10^{-15})

p – pico (10^{-12})

n – nano (10^{-9})

μ – micro (10^{-6})

m – milli (10^{-3})

k – kilo (10^3)

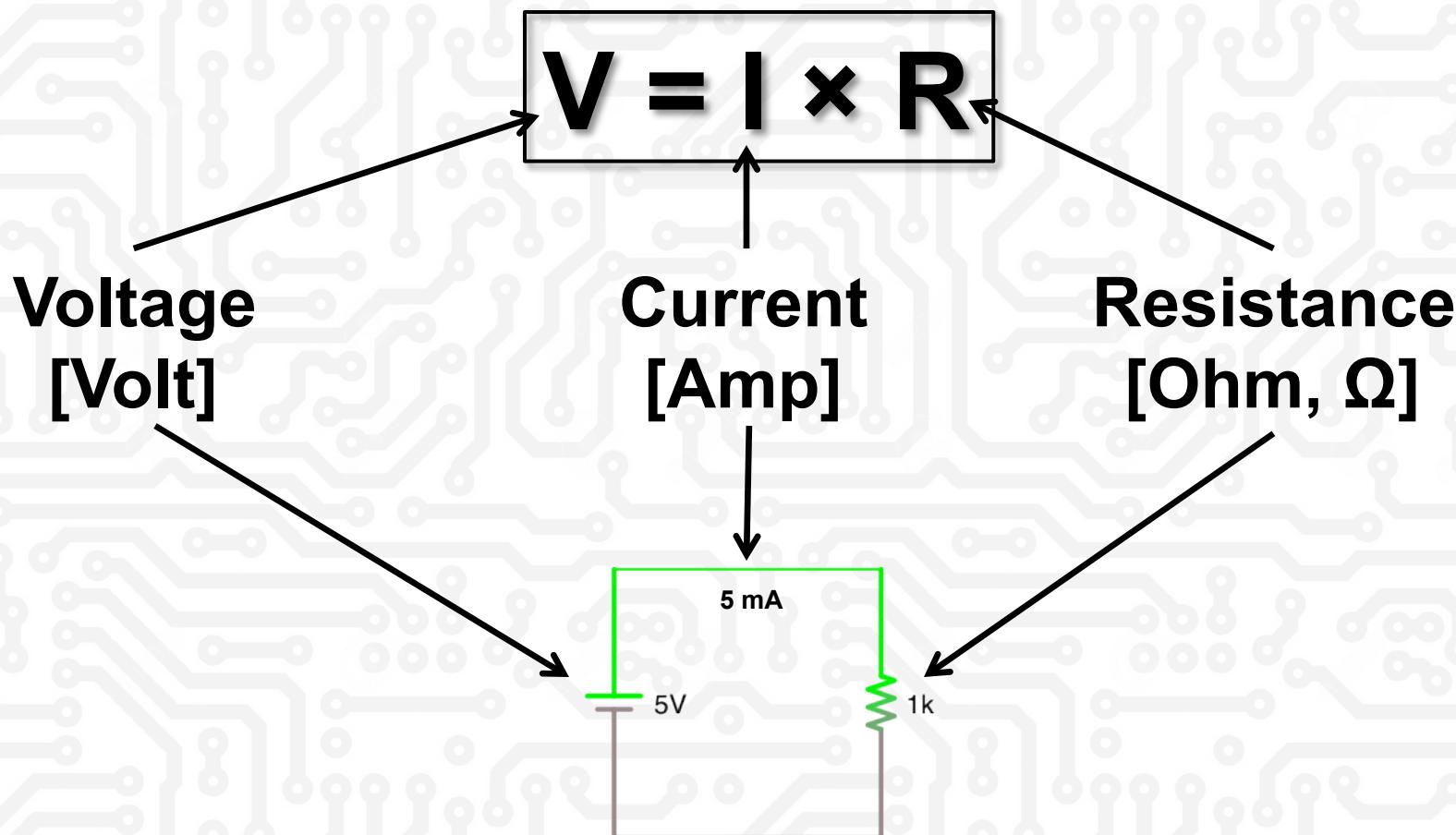
M – mega (10^6)

G – giga (10^9)

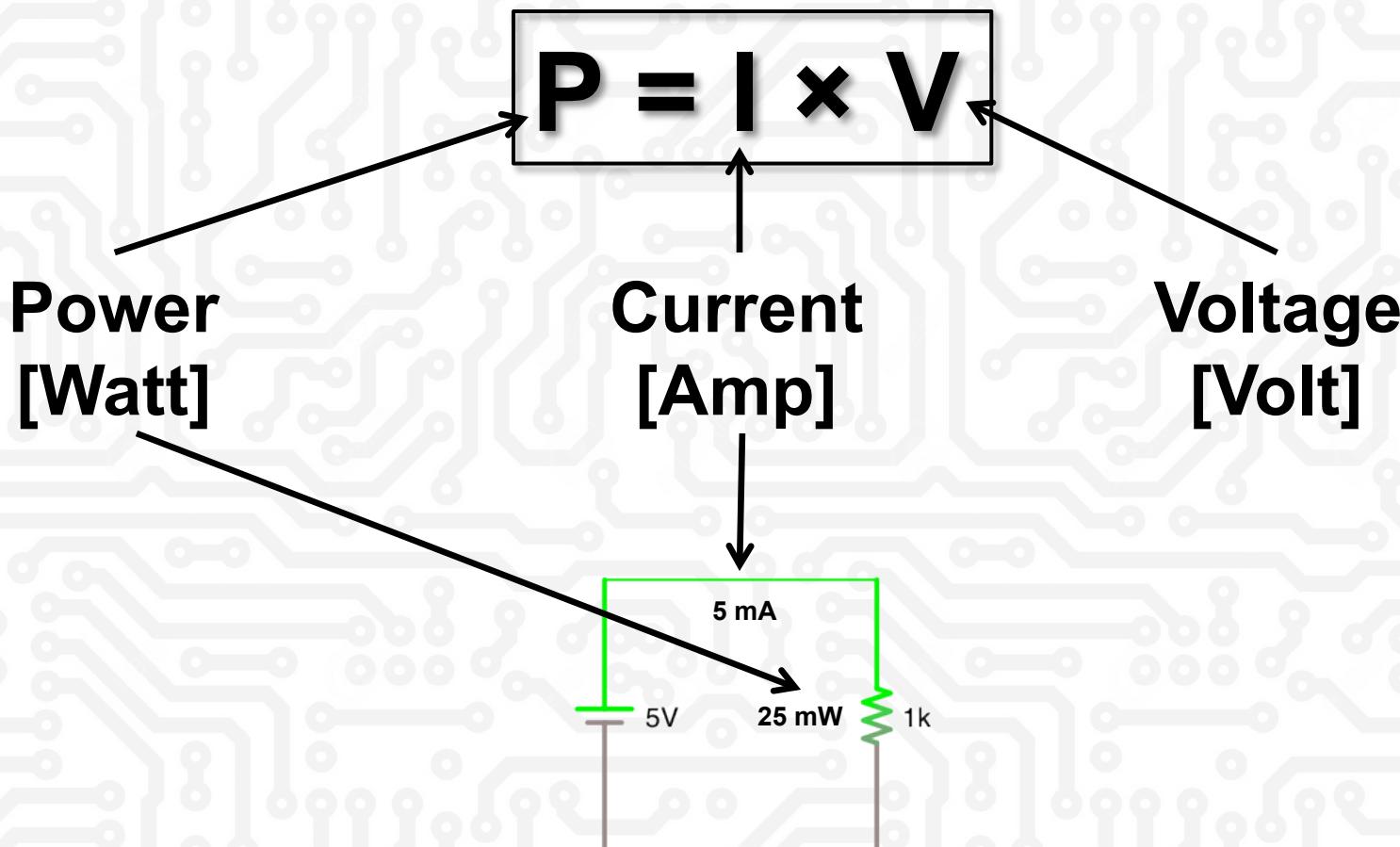
T – tera (10^{12})

P – peta (10^{15})

Ohm's Law



Power



The Gravitational Force



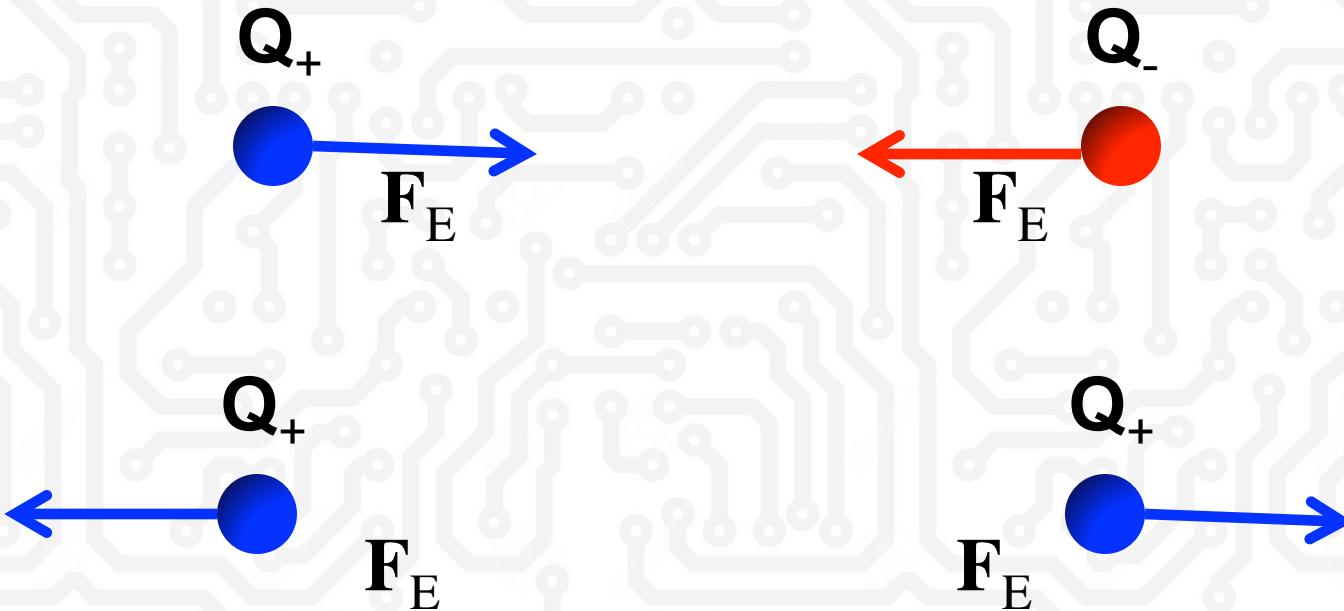
$$F_G = \frac{GMm}{r^2}$$

Diagram illustrating the components of the gravitational force equation:

- Coupling constant: G
- Masses or charges: M and m
- Inverse-square of separation: r^2

JAXA, 2015

The Electrostatic Force



$$F_E = \frac{kQ_+Q_-}{r^2}$$

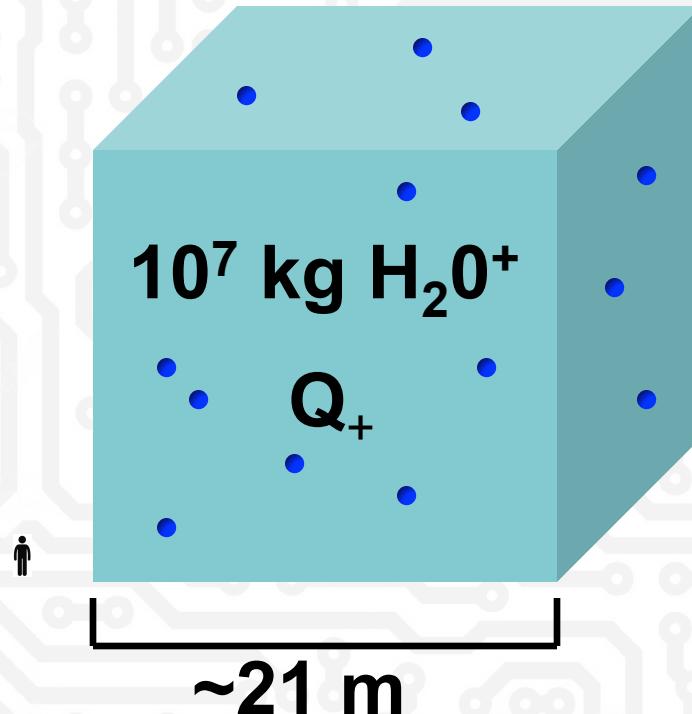
How much charge would it take to replicate the gravitational force between the Earth and Moon?



$$F_E = \frac{kQ_+Q_-}{r^2}$$

JAXA, 2015

**It turns out to be a very small amount:
A few swimming pools or a small
pond's worth of water**



$$\begin{aligned} &3 \times 10^{32} \text{ elementary charges} \\ &= 5 \times 10^{13} \text{ Coulomb} \end{aligned}$$

Van de Graaff generator charge $\sim 1 \mu\text{C}$

So why isn't the Universe dominated by charges forcing each other around?



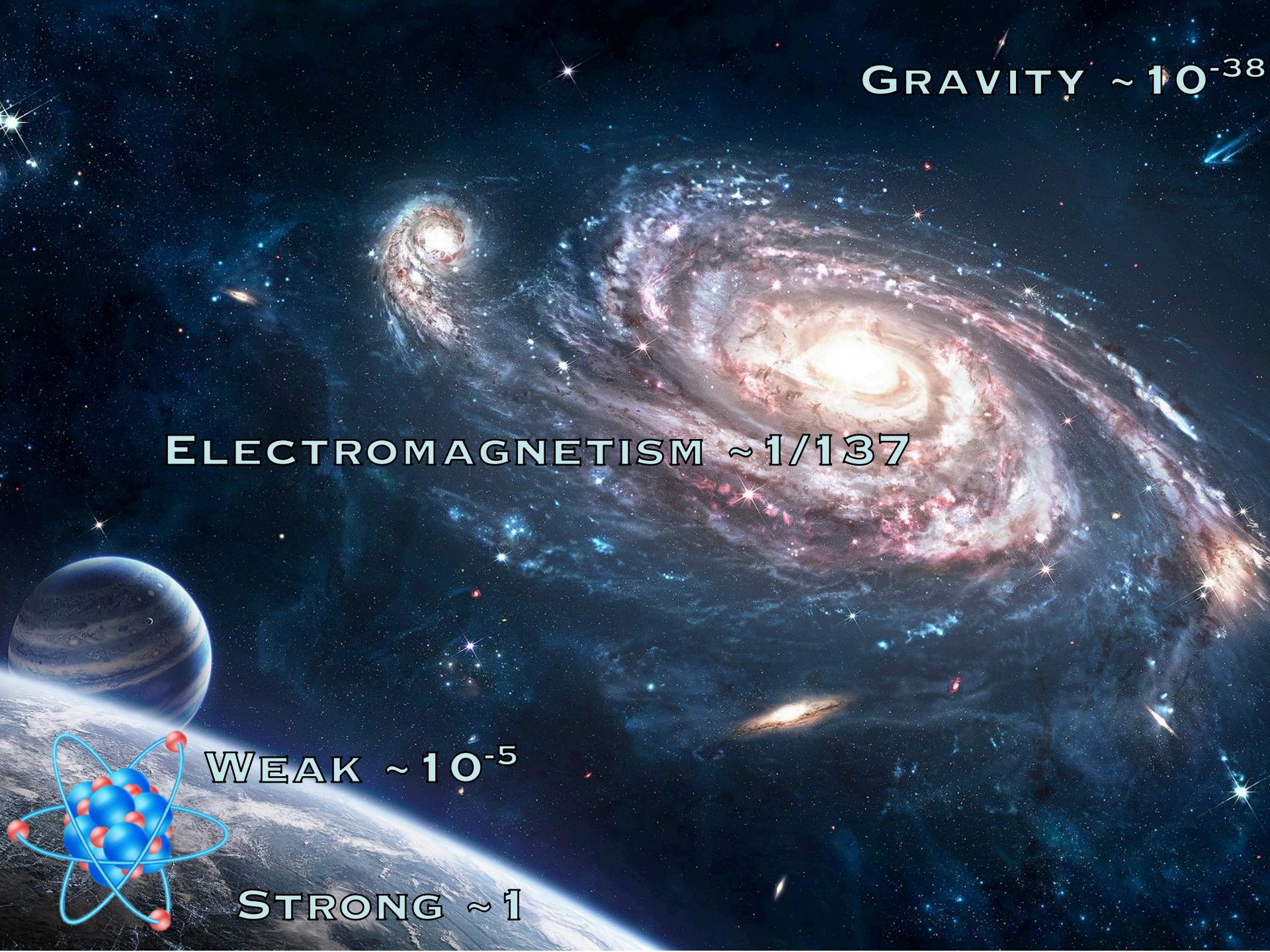
So why isn't the Universe dominated by charges forcing each other around?



It is!

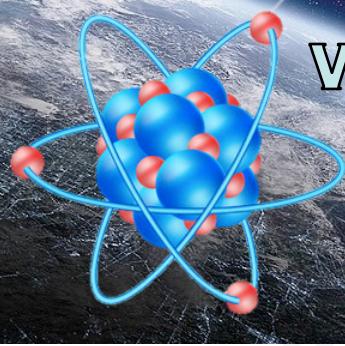
Virtually everything in our experience is a product of the Electromagnetic Force

- Holds electrons & protons together in atoms
- Holds atoms together in compounds:
Chemistry
- All electromagnetic radiation:
 - Radio, Microwave, Infrared, Optical, Ultraviolet, X-ray, γ-ray



GRAVITY $\sim 10^{-38}$

ELECTROMAGNETISM $\sim 1/137$

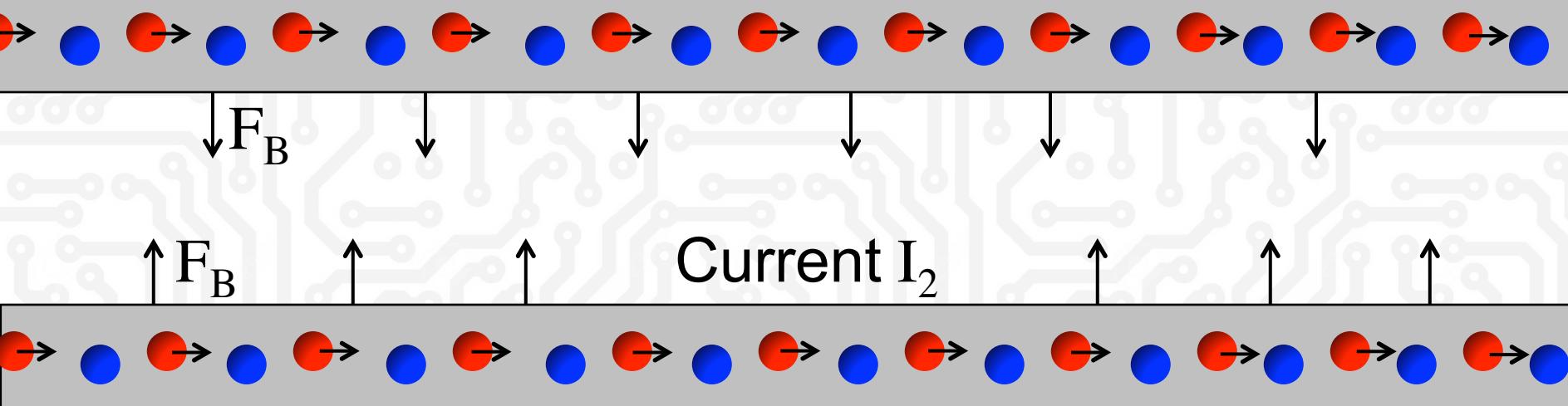


WEAK $\sim 10^{-5}$

STRONG ~ 1

The Magnetic Force

Current I_1 moving distance dl_1



$$F_B = \frac{\mu_0}{4\pi} \frac{I_1 dl_1 \bullet I_2 dl_2}{r^2}$$

The dot, \bullet , means that parallel currents attract, antiparallel currents repel

Fields

$$F_G = \frac{GMm}{r^2} = \left(\frac{GM}{r^2} \right) m = mg$$

$$F_E = \frac{kQ_1Q_2}{r^2} = \left(\frac{kQ_1}{r^2} \right) Q_2 = Q_2 E$$

$$F_B = \frac{\mu_0}{4\pi} \frac{I_1 dl_1 \bullet I_2 dl_2}{r^2} = \left(\frac{\mu_0}{4\pi} \frac{I_1 dl_1}{r^2} \right) \bullet I_2 dl_2 = I_2 dl_2 \times B$$

The gravitational field at the surface of the Earth:

$$g = 9.8 \text{ m/s}^2$$

E is the electric field

B is the magnetic field

The cross, \times , allows us to generalize the direction of the field

Let's break that last line up

$$B = \frac{\mu_0}{4\pi} \frac{I_1 dl_1 \times \hat{r}}{r^2}$$

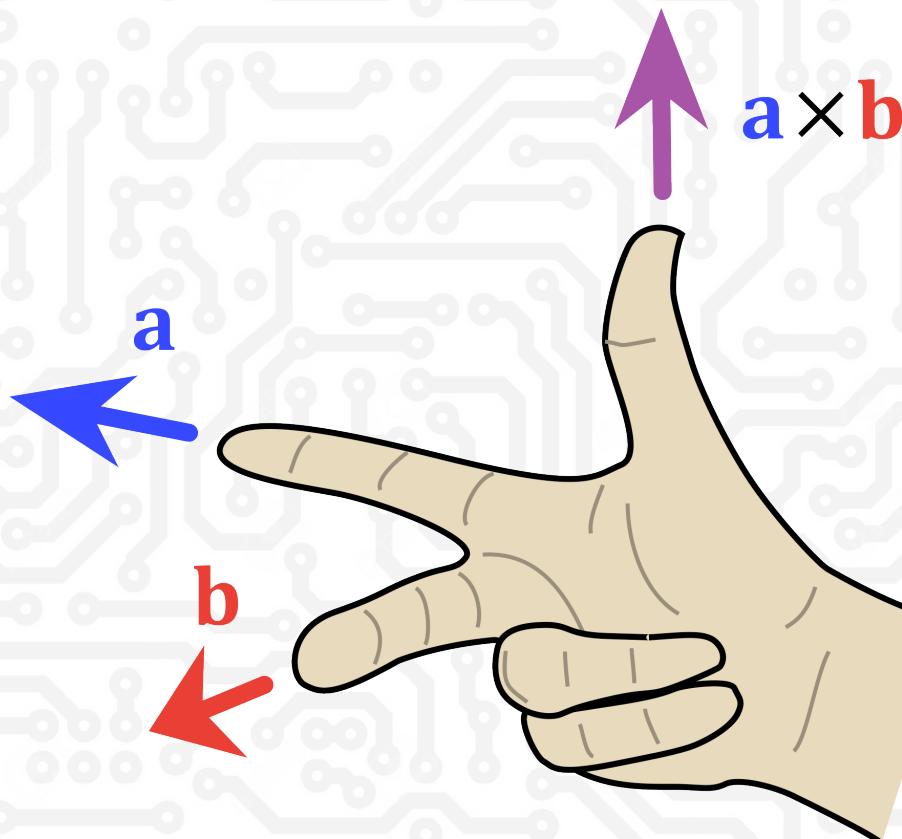
Biot-Savart Law tells how currents create B-fields

$$F_B = I_2 dl_2 \times B$$

Lorentz Force is the force on current 2 by the B-field of current 1

We have replaced the dot, •, that meant parallel currents attract, with two ×'s.
These are cross-products.

The Right-Hand Rule



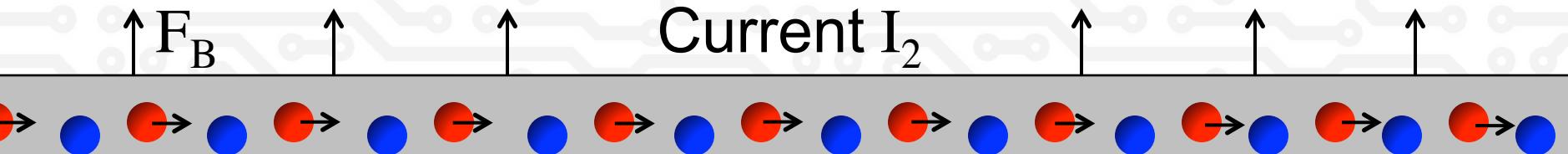
The Magnetic Force

Current I_1 moving distance dl_1



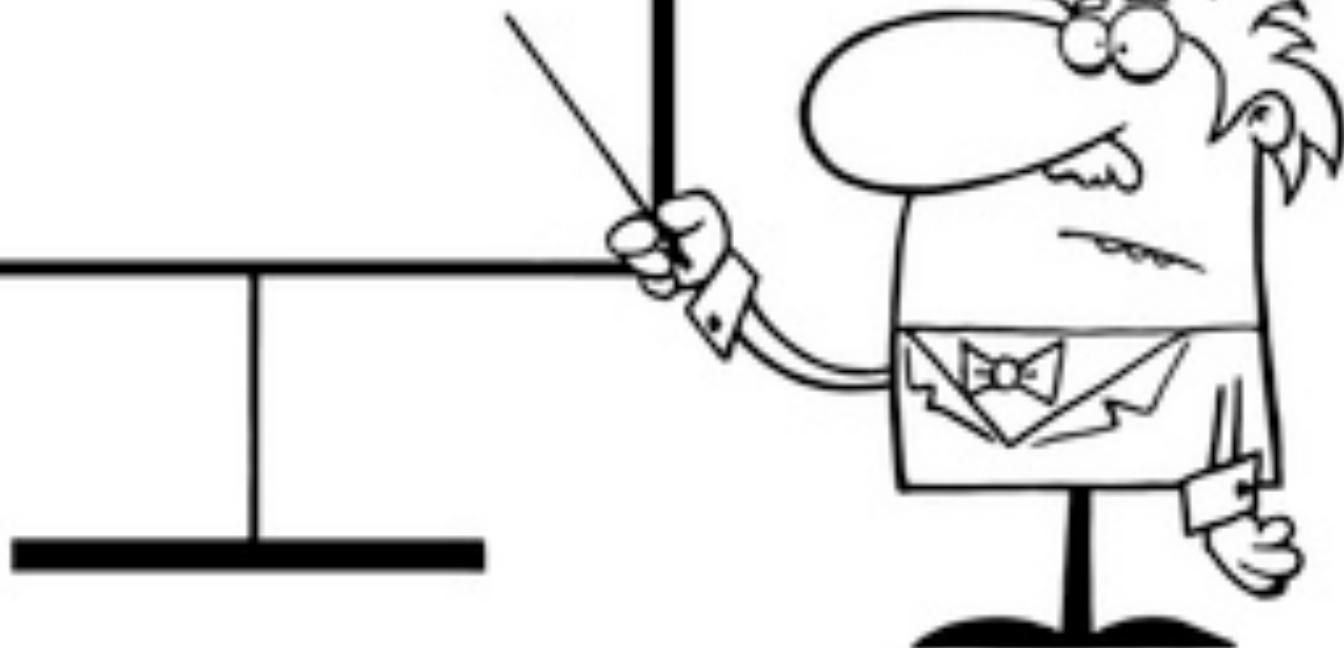
Biot-Savart: $B \sim dl_1 \times r$ is into the screen

Lorentz Force: $F_B \sim dl_2 \times B$ is upward

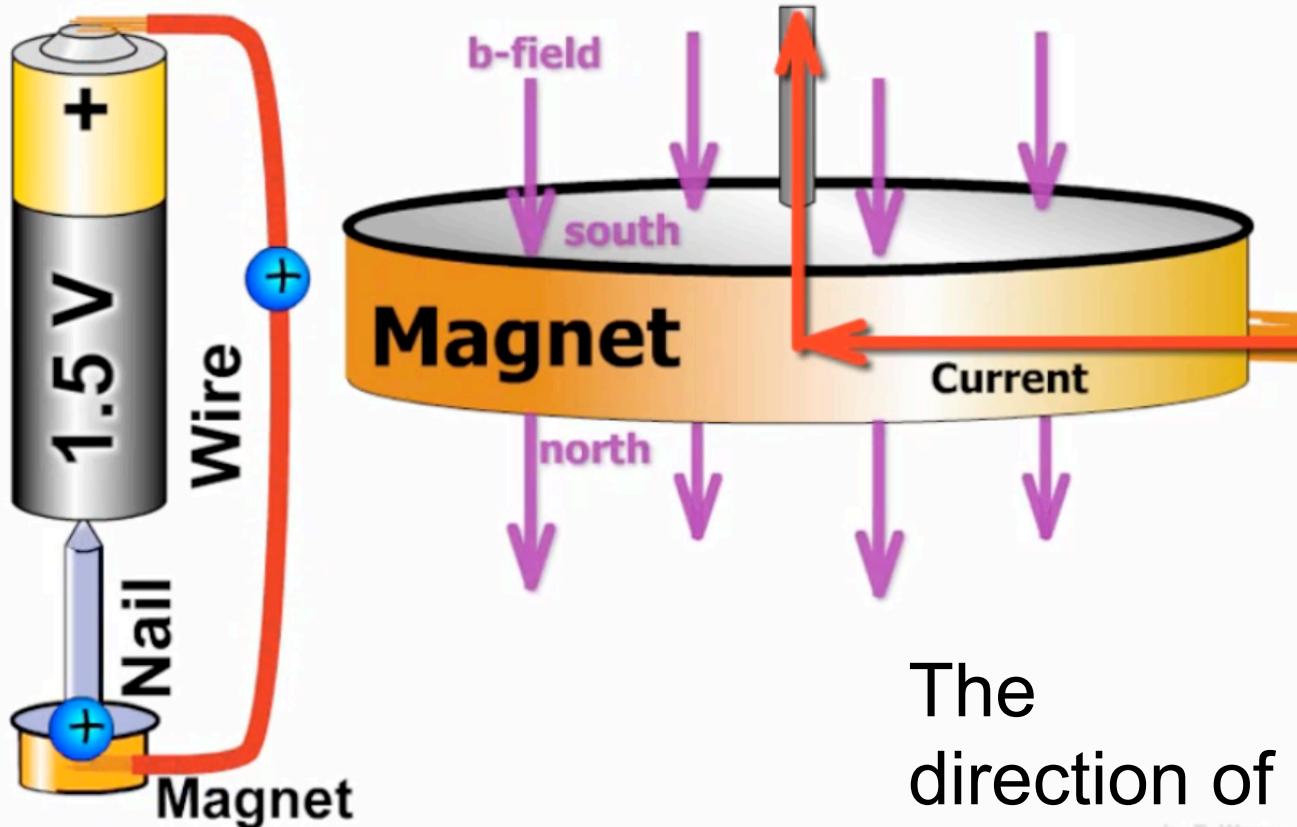


This two-step process gives the same answer.

**Time For a
Demonstration**



The Homopolar Motor



The
direction of
 $F_B \sim dl_2 \times B$
is?

by T. Wayne

By the Numbers

**Our Neodymium magnet has
Surface magnetic field $B \approx 0.3 \text{ T}$**

Density $\rho = 8.6 \times 10^3 \text{ kg/m}^3$

Radius $R = \frac{1}{4}'' = 6 \text{ mm} = 6 \times 10^{-3} \text{ m}$

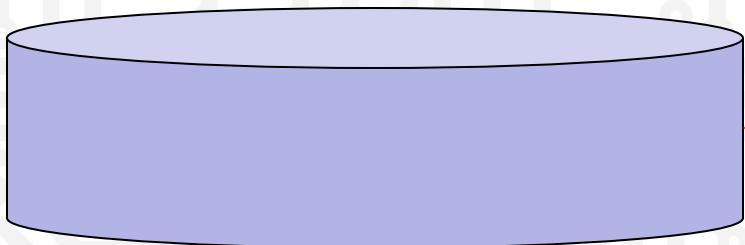
Height $H = 5 \text{ mm} = 5 \times 10^{-3} \text{ m}$

Mass $M = \rho V = 2\pi\rho R^2 H \approx 8.6 \text{ gm}$

Moment of Inertia $I = \frac{1}{2} MR^2 = 7.7 \times 10^{-8} \sim 10^{-7} \text{ kg-m}^2$

By the Numbers

$$F_B \sim I_2 dI_2 B = 3 \times 10^{-3} \text{ Newtons}$$



The current is
 $I_2 \sim 1.0 \text{ Amp}$

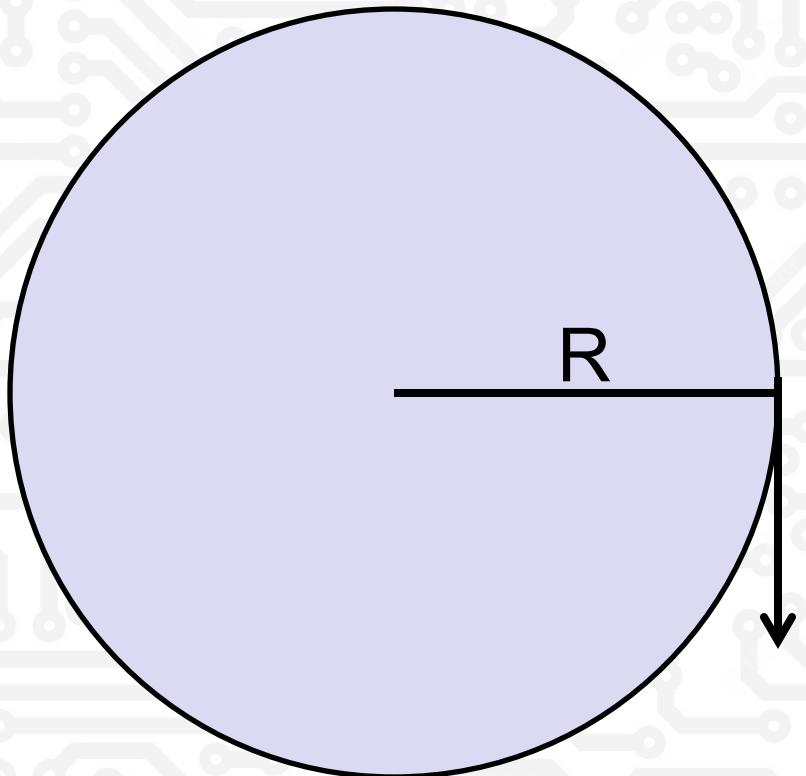
and it crosses
a region of field
 $dI_2 \sim 1 \text{ mm} = 10^{-3} \text{ m}$



$$I_2 \sim 1.0 \text{ Amp}$$

$$\downarrow \quad B \sim 0.3 \text{ T}$$

By the Numbers



$$\begin{aligned}\text{Torque } \tau &= F_B \times R \\ &= (3 \times 10^{-3}) (6 \times 10^{-3}) \\ &= 1.8 \times 10^{-6} \text{ N-m}\end{aligned}$$

Newton's force law for rotation:

$$\tau = I\omega'$$

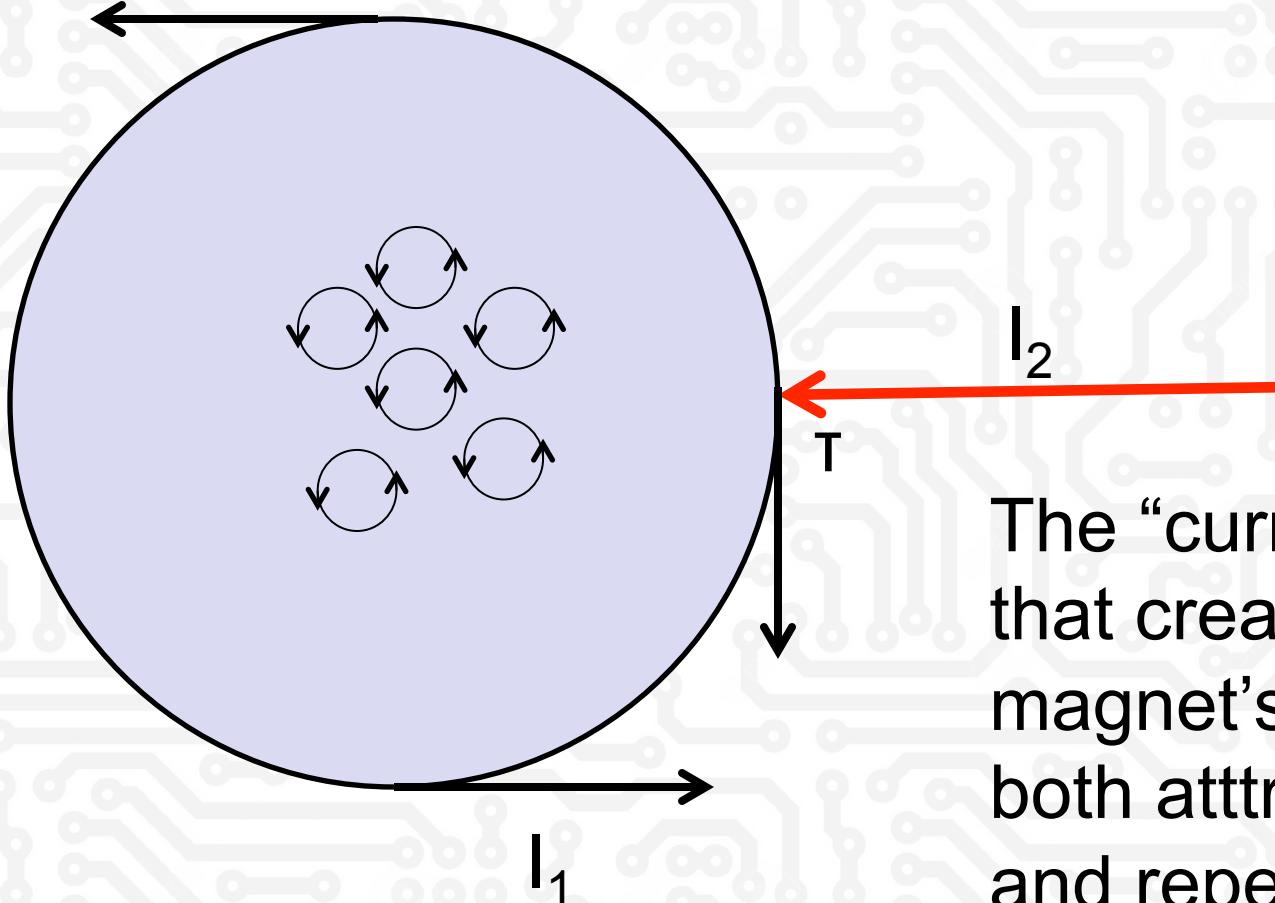
So

$$\omega' = \tau/I \approx 180 \text{ s}^{-2}$$

$$\begin{aligned}f' &= \omega'/2\pi \approx 30 \text{ s}^{-2} \\ &= 30 \text{ Hz/s}\end{aligned}$$

So in about 1 second the disk speeds up to a frequency of ~ 30 Hz

But Why does it spin? Go back to the current picture



The “current” I_1 that creates the magnet’s B-field both attracts (top) and repels (bottom) the incoming current I_2

Summary

- Ohm's Law $V = I \times R$
- Power $P = I \times V$
- Electromagnetics underpins our world and this course
- Introduction of Magnetic field
- The Homopolar Motor
 - Magnetic Field Picture
 - Current Picture

