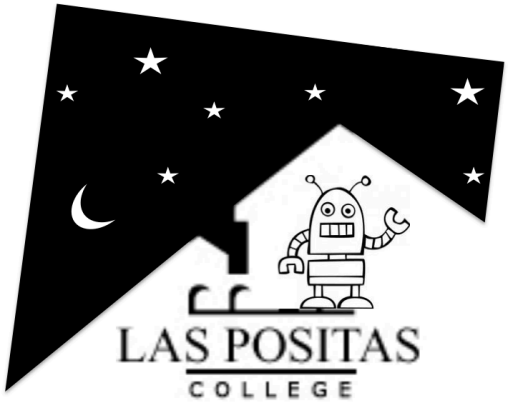
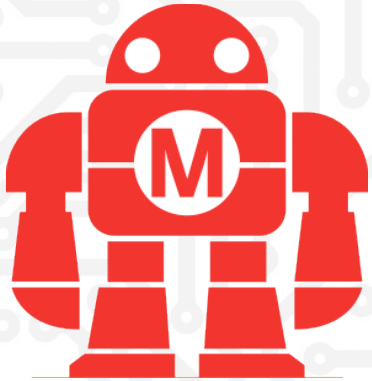
Making Makers





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})

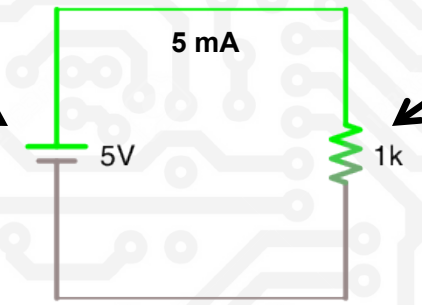
Ohm's Law

$$V = I \times R$$

Voltage [Volt]

Current [Amp]

Resistance [Ohm, Ω]



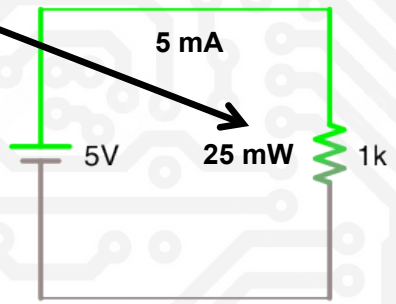
Power

$$P = I \times V$$

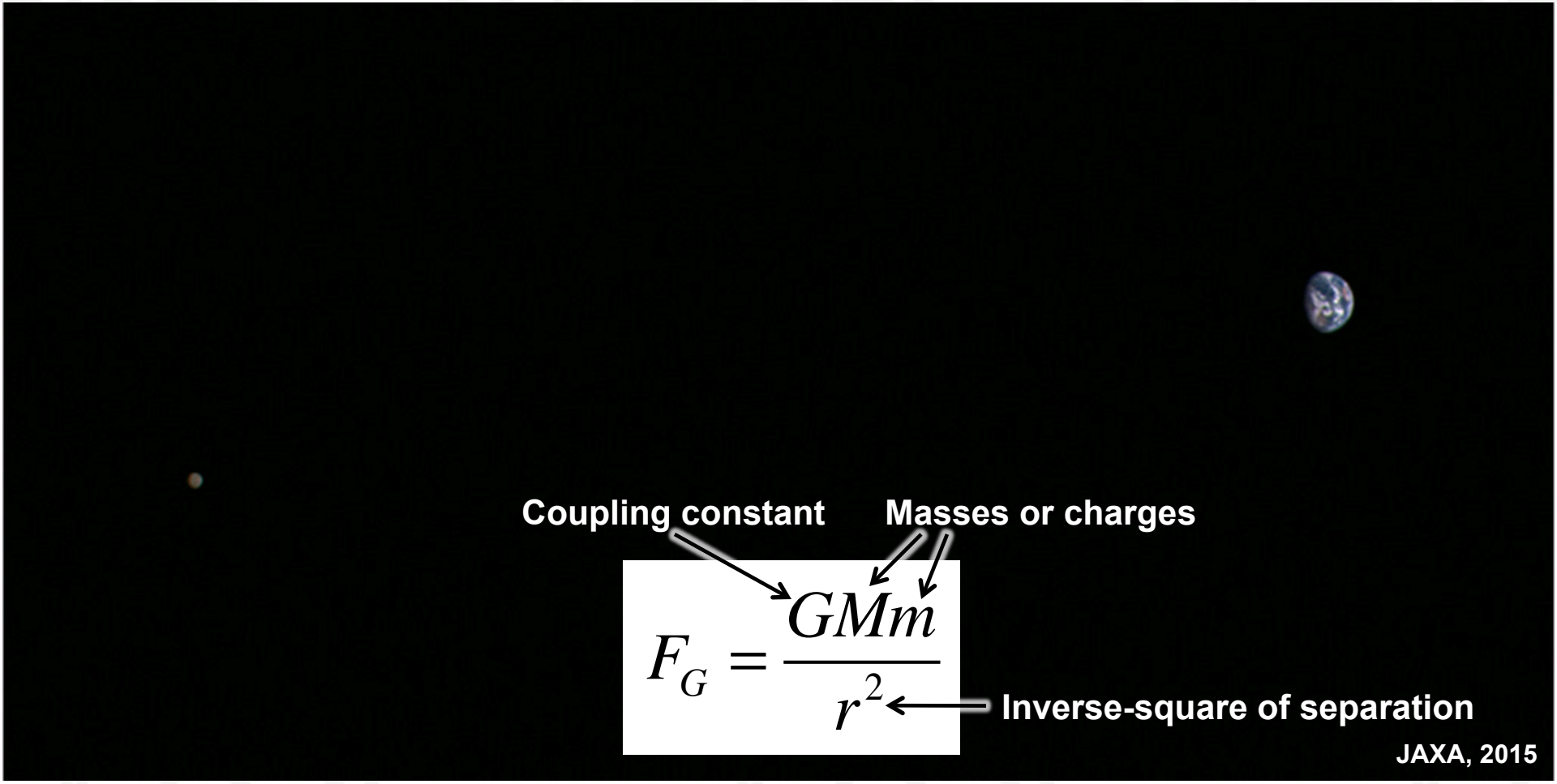
Power [Watt]

Current [Amp]

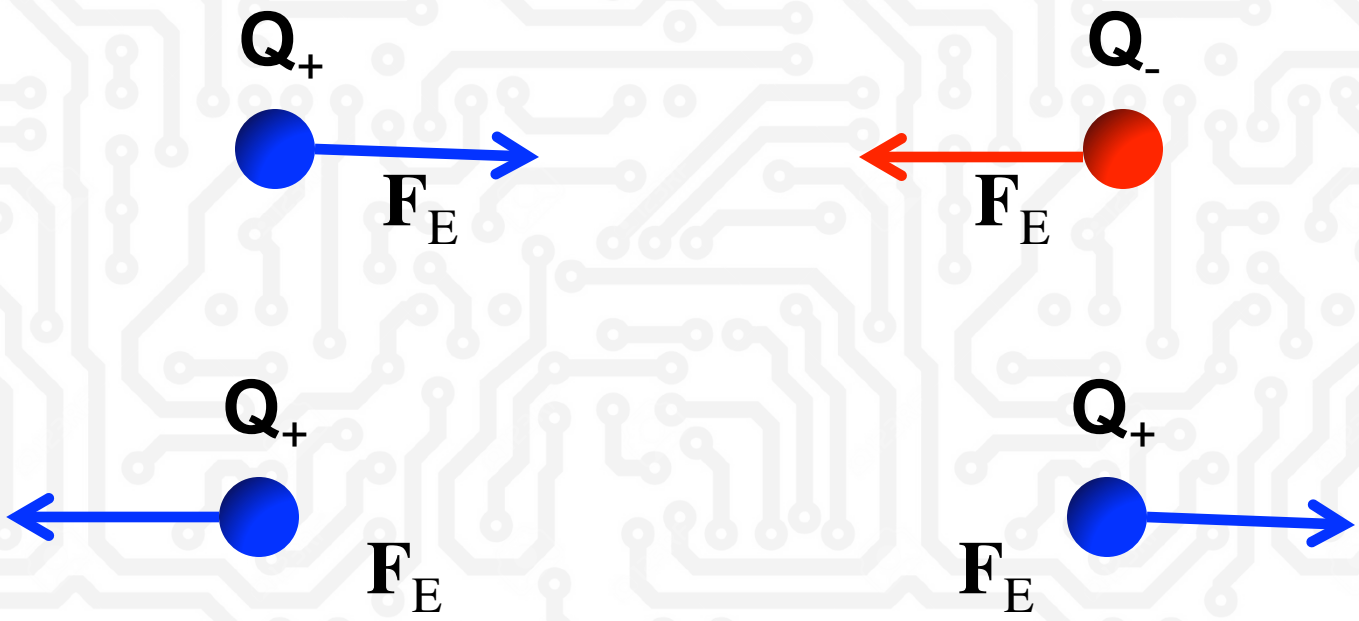
Voltage [Volt]



The Gravitational Force

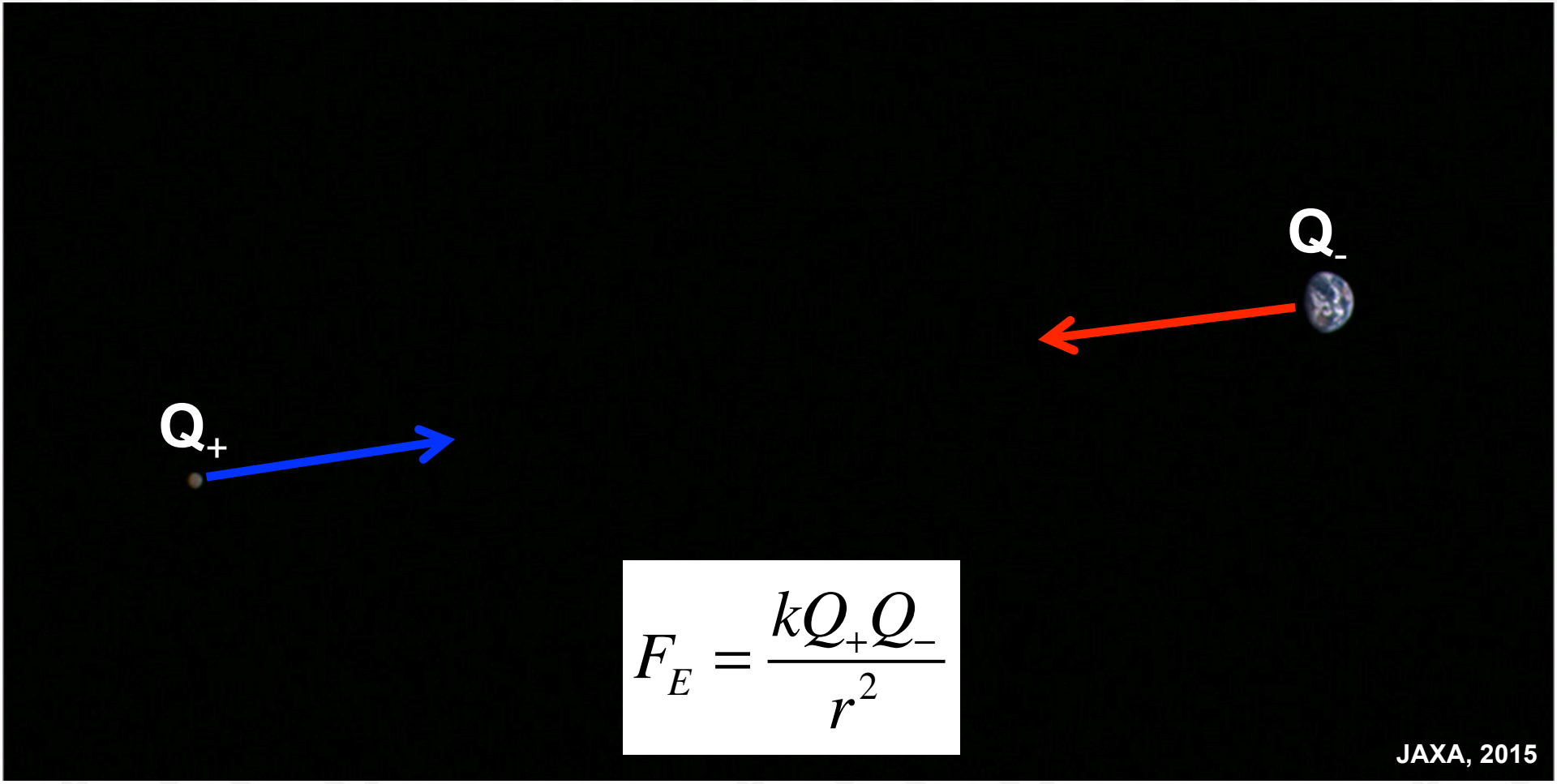


The Electrostatic Force



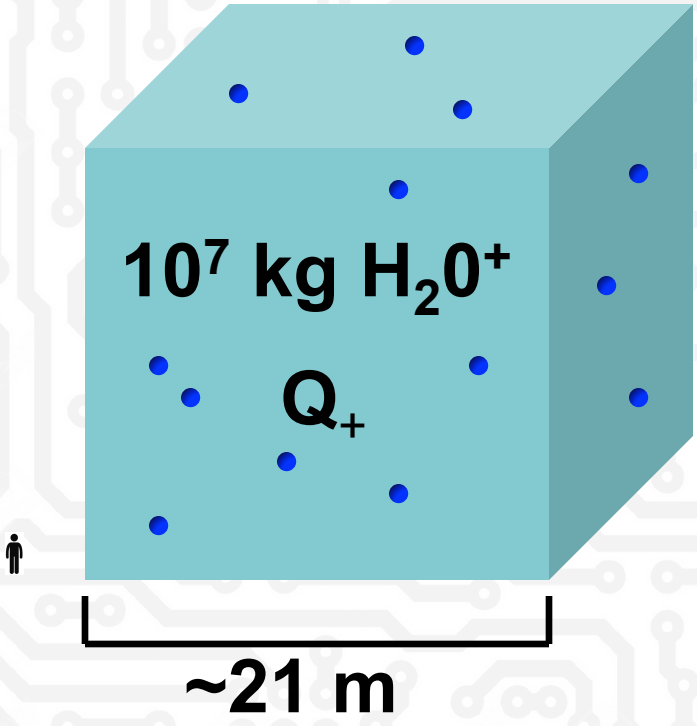
$$F_E = \frac{kQ_+Q_-}{r^2}$$

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



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

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



3×10^{32} elementary charges
$= 5 \times 10^{13}$ Coulomb

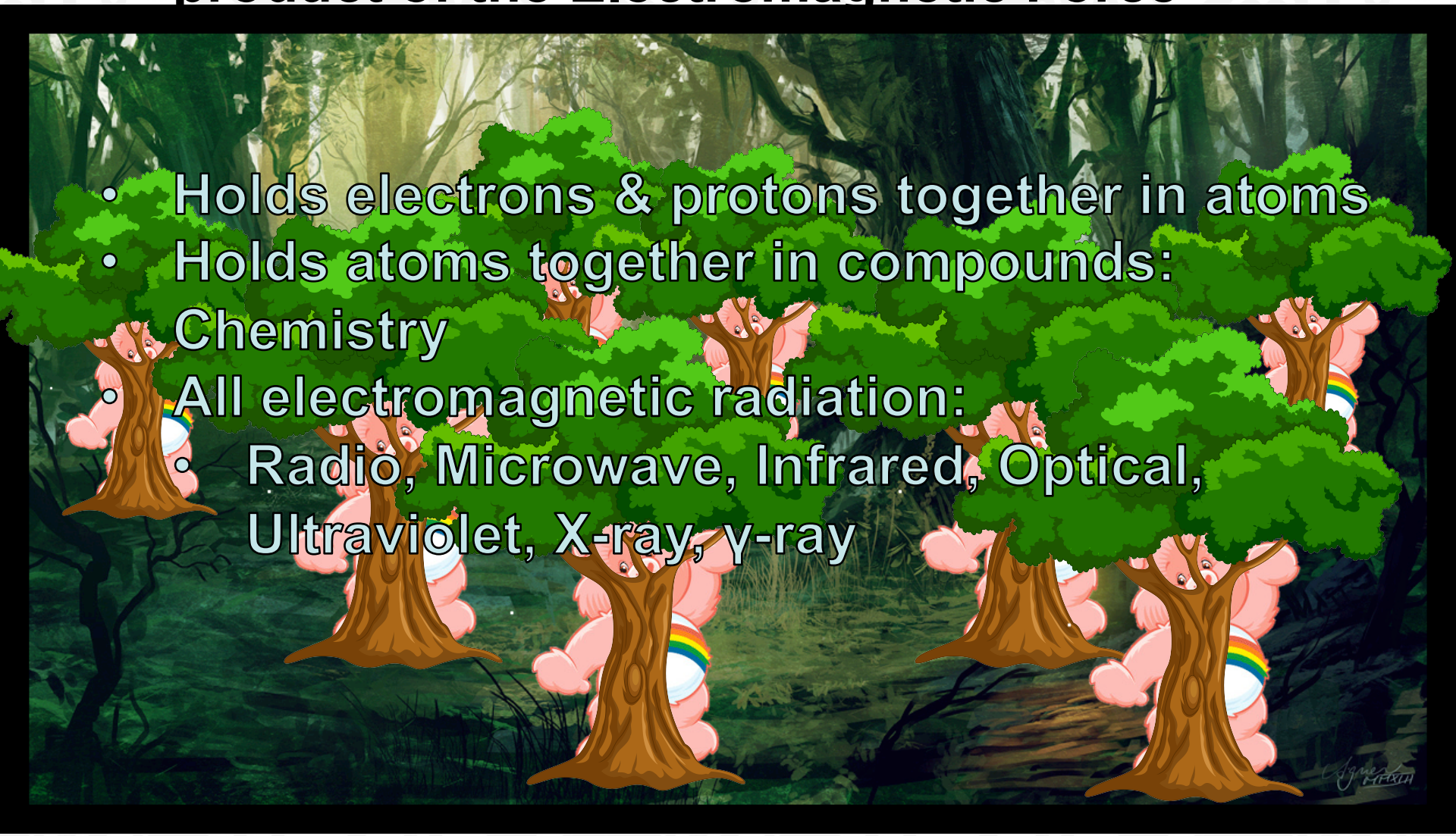
Van de Graaff generator charge ~ 1 μC

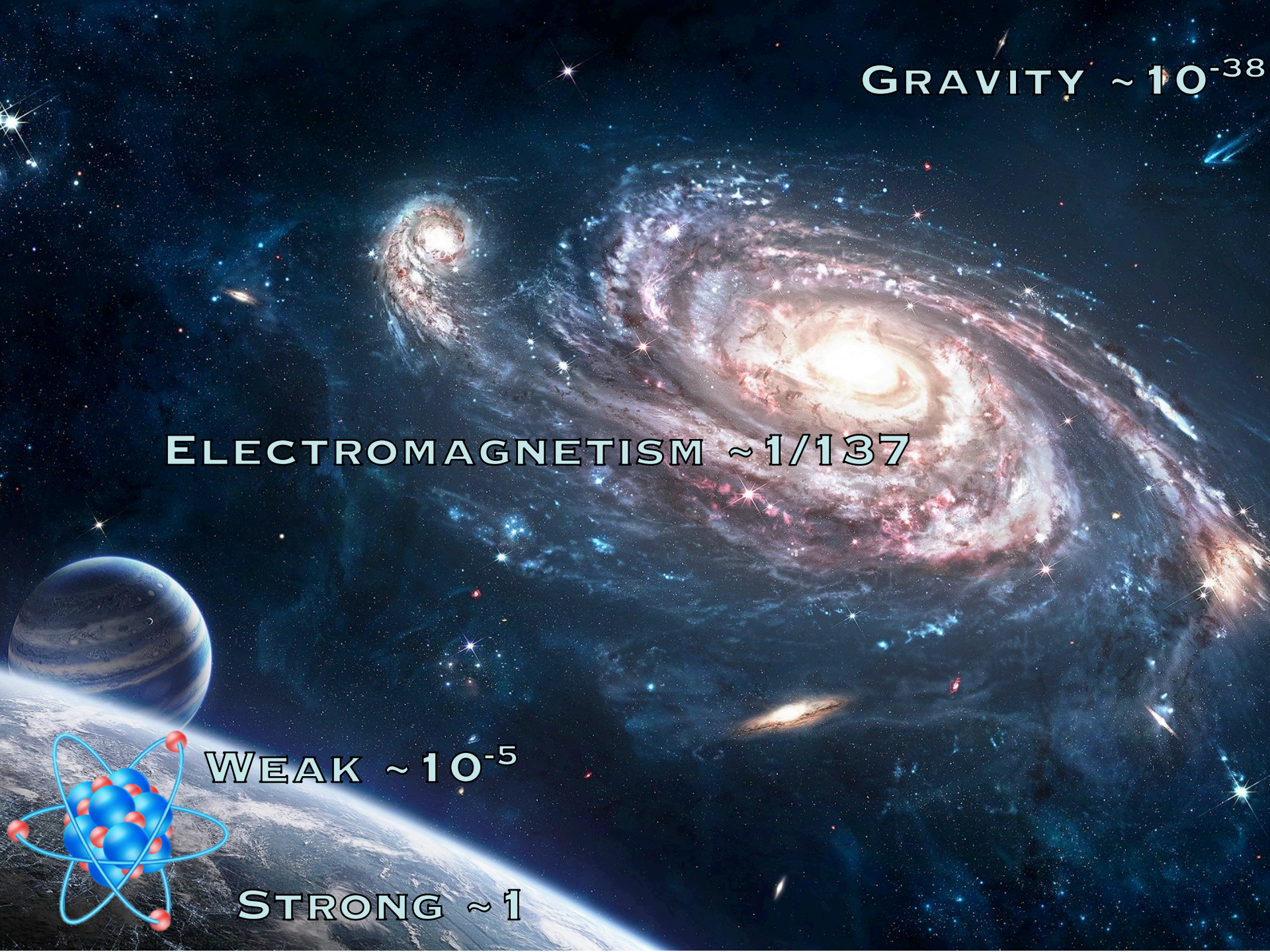
So why isn't the Universe dominated by charges forcing each other around?

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

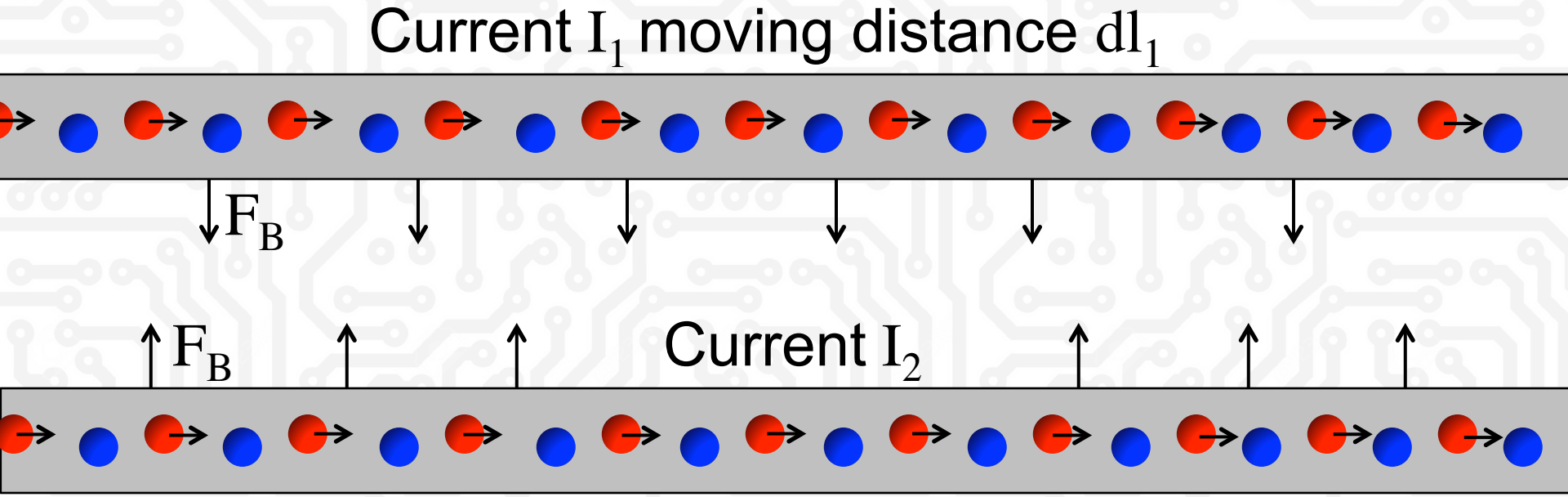
It is!

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




Gravity ~ 10^{-38}
Electromagnetism ~ 1/137
Weak ~ 10^{-5}
Strong ~ 1

The Magnetic Force



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

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

Fields

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

The graviational field at the surface of the Earth:

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

$$F_E = \frac{kQ_1Q_2}{r^2} = \left(\frac{kQ_1}{r^2}\right)Q_2 = Q_2E$$

E **is the electric field**

$$F_B = \frac{\mu_0}{4\pi}\frac{I_1dl_1 \bullet I_2dl_2}{r^2} = \left(\frac{\mu_0}{4\pi}\frac{I_1dl_1}{r^2}\right) \bullet I_2dl_2 = I_2dl_2 \times B$$

B **is the magnetic field**

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

Let's break that last line up

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

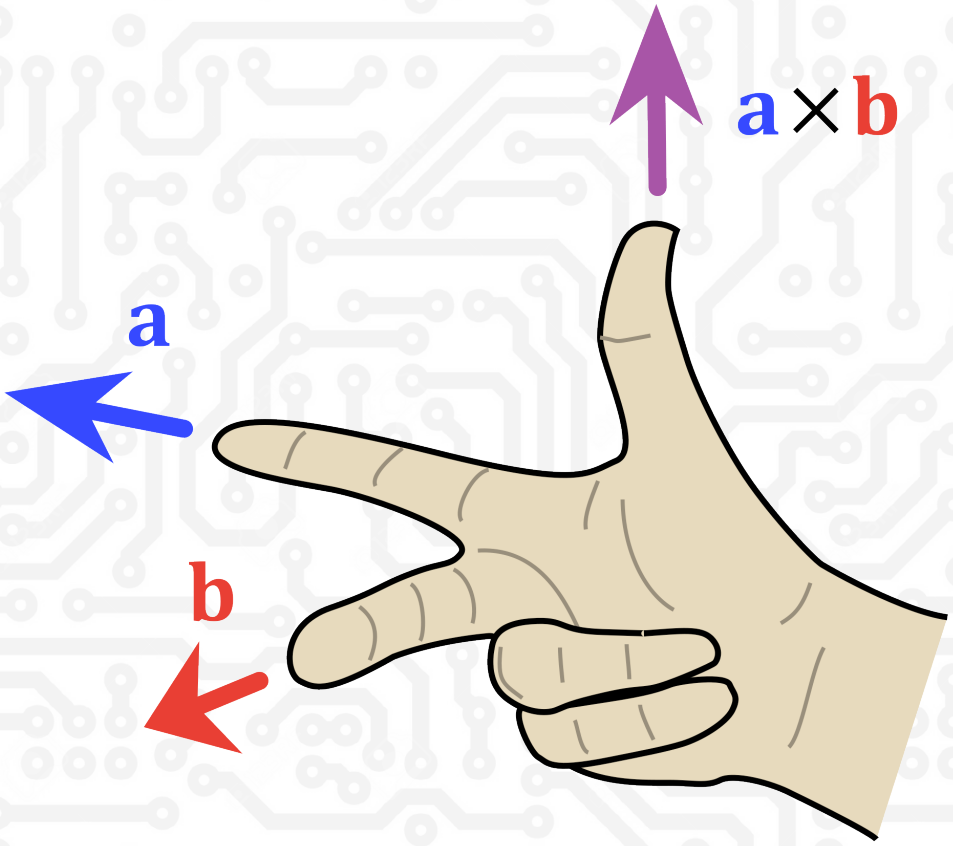
Biot-Savart Law **tells how currents create B-fields**

$$F_B = I_2 dl_2 \times B$$

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

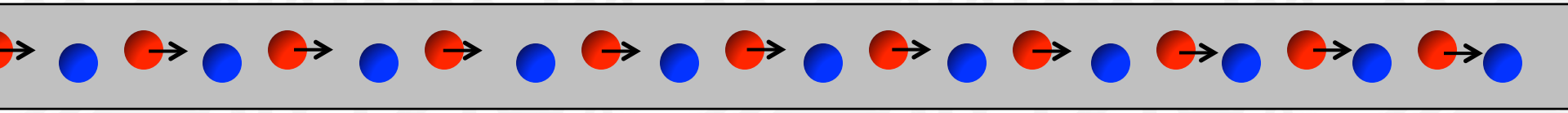
We have replaced the dot, $\bullet$, that meant parallel currents attract, with two $\times$'s. These are cross-products.

The Right-Hand Rule



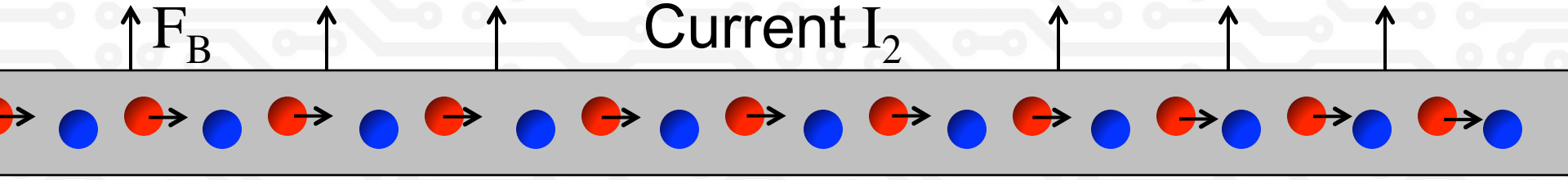
The Magnetic Force

Current I_1 moving distance dl_1

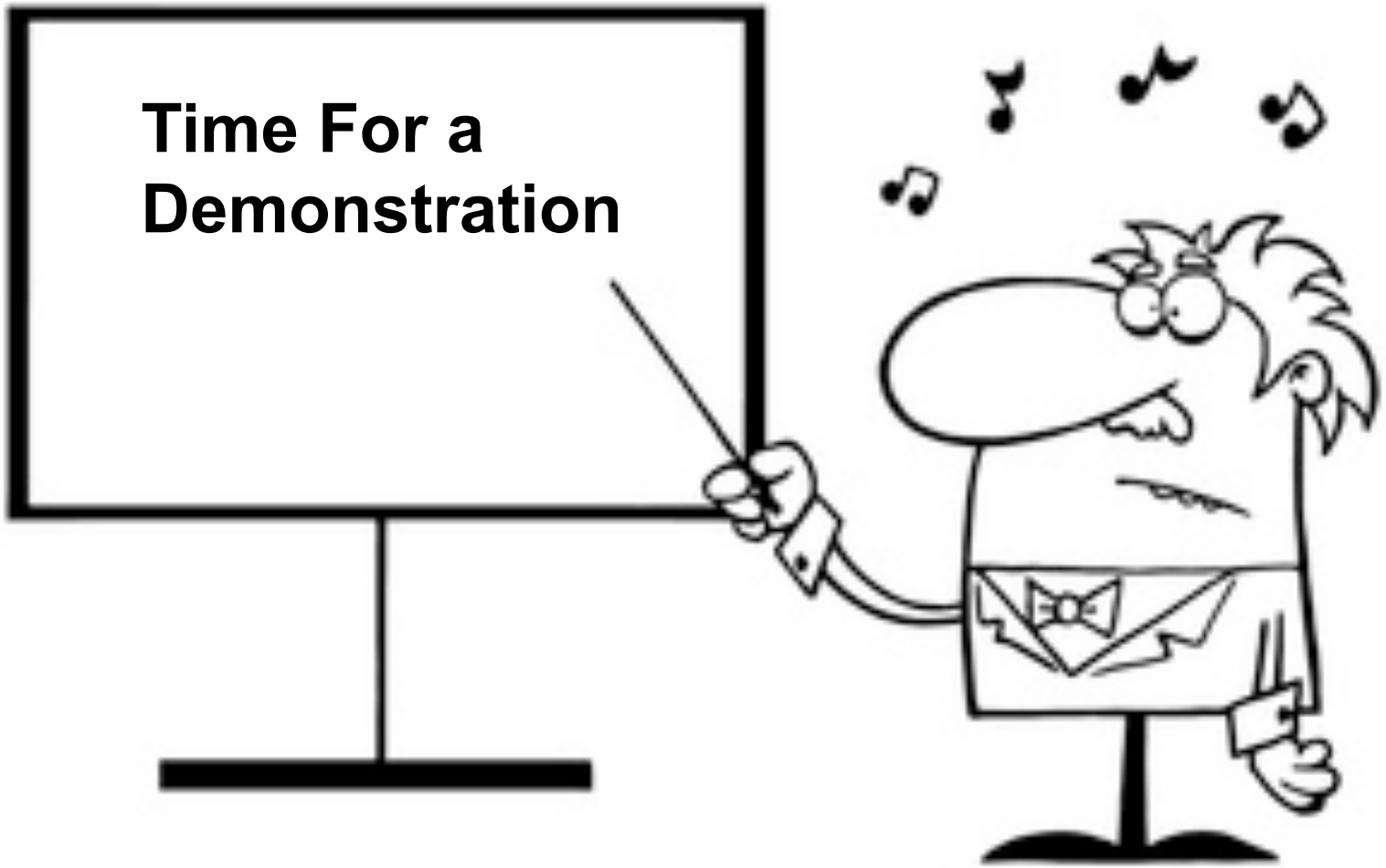


Biot-Savart: $B \sim dl_1 \times r$ is into the screen

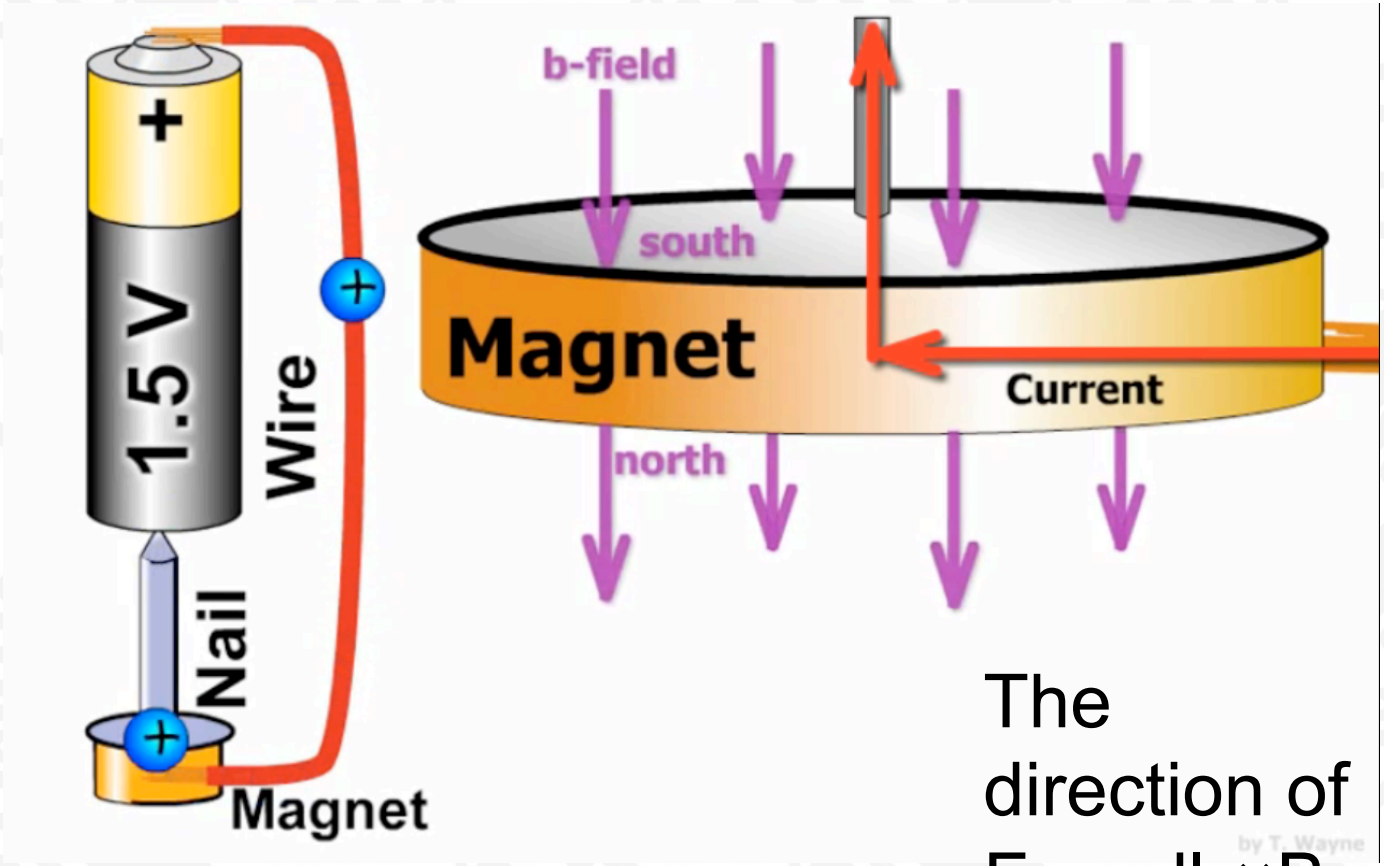
Lorentz Force: $F_B \sim dl_2 \times B$ is upward



This two-step process gives the same answer.



The Homopolar Motor



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

By the Numbers

Our Neodymium magnet has
Surface magnetic field B ≈ 0.3 T
Density ρ = 8.6 × 10^3 kg/m^3
Radius R = ¼" = 6 mm = 6 × 10^{-3} m
Height H = 5 mm = 5 × 10^{-3} m

Mass $$M = \rho V = \pi \rho R^2 H \approx 5$$ gm

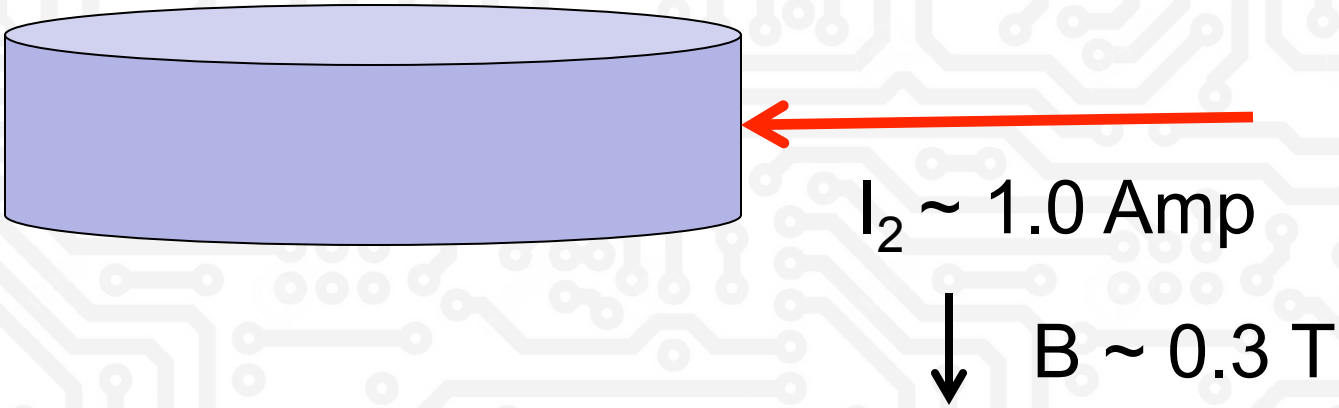
Moment of Inertia $$I = \tfrac{1}{2} M R^2 \sim 10^{-7}$$ kg-m

By the Numbers

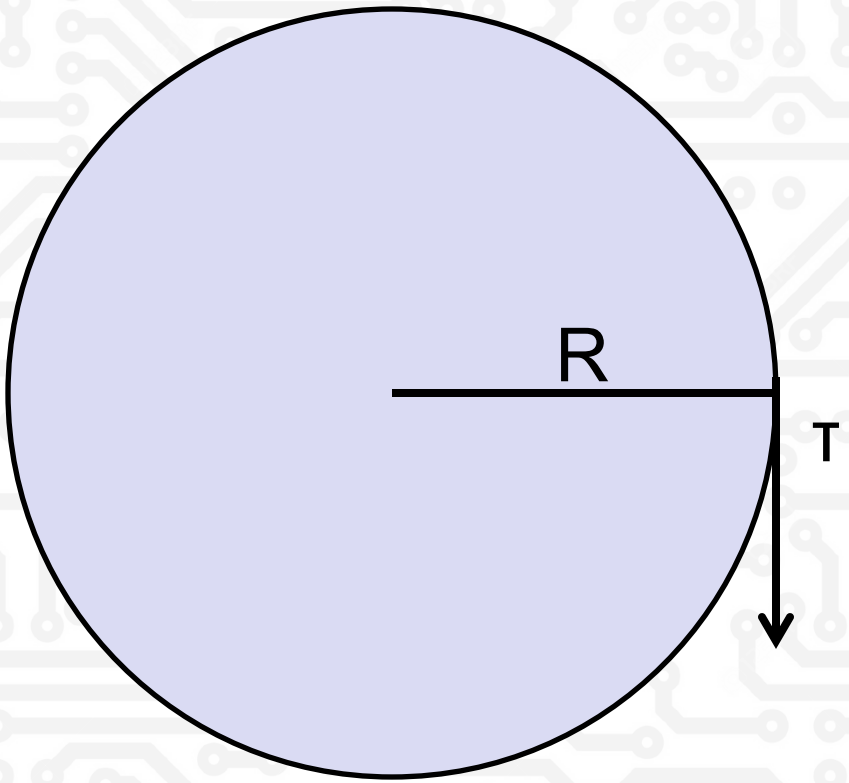
$F_B \sim I_2\, dl_2\, B =$
6×10^{-4} Newtons

The current is (as established in class)
$I_2 \sim 2.0$ Amp ~ 1.5 V / 0.7 Ω

and and it crosses
a region of field
$dl_2 \sim 1$ mm $= 10^{-3}$ m



By the Numbers



Torque $\tau = F_B \times R$
$= (6 \times 10^{-4})\ (6 \times 10^{-3})$
$= 3.6 \times 10^{-6}$ N-m

Newton's force law for rotation:

$\tau = I\omega'$

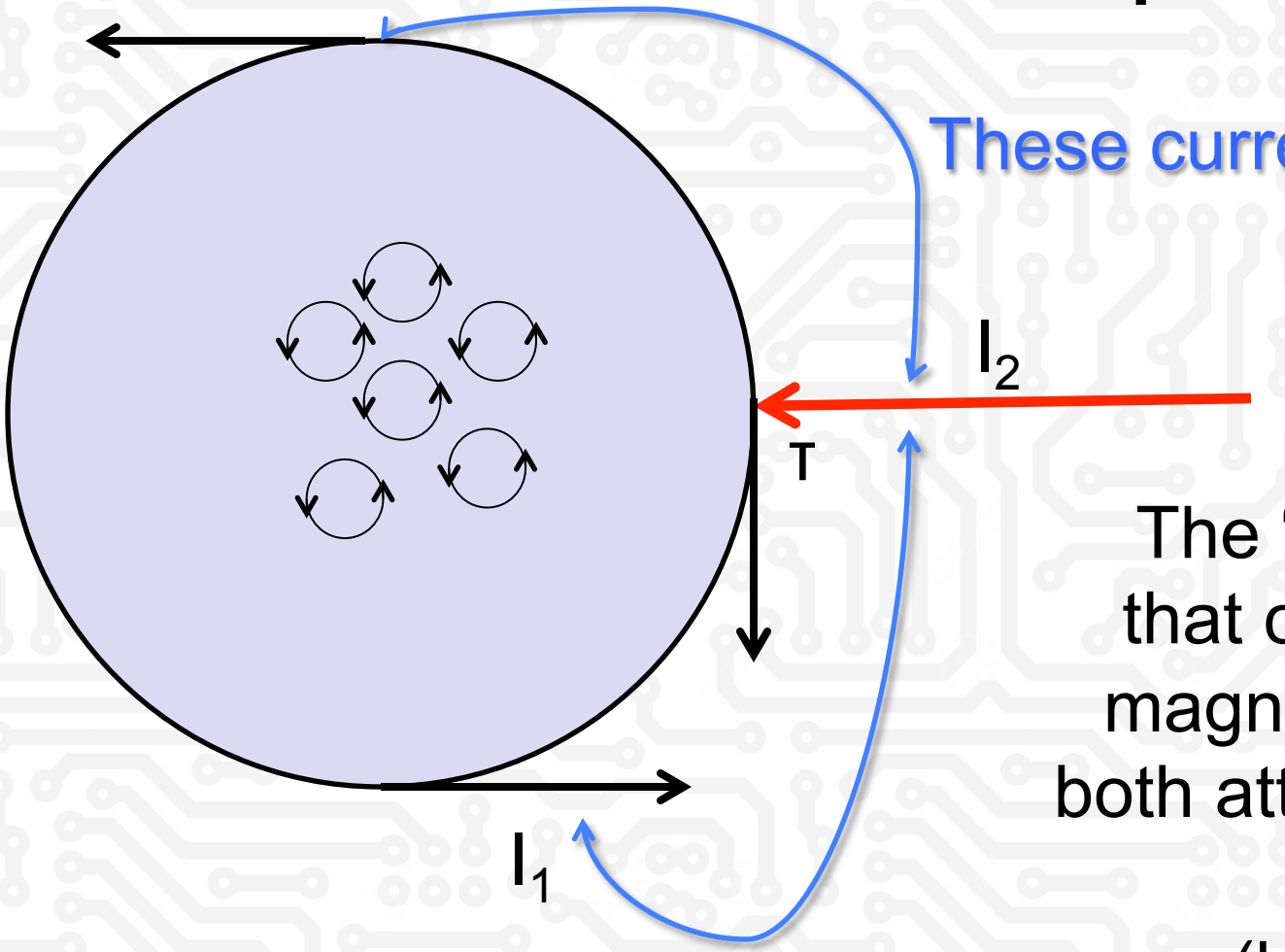
So

$\omega' = \tau/I \approx 36\ s^{-2}$

$f' = \omega'/2\pi \approx 6\ s^{-2}$
$= 6$ Hz / s

So in about 1 second the disk speeds up to a frequency of ~ 6 Hz
A reasonable number.

But <u>why</u> 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 x R
- Power P = I x V
- Electromagnetics underpins our world and this course
- Introduction of Magnetic field
- The Homopolar Motor
  - Magnetic Field Picture
  - Current Picture