Making Makers

LAS POSITAS COLLEGE

ARDUINO™

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})

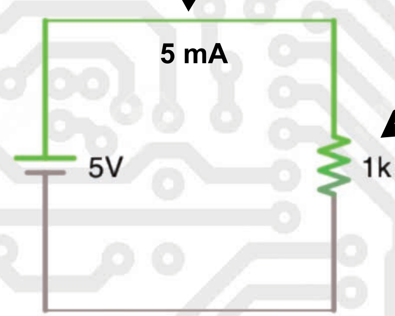
Ohm's Law

$$\boxed{V = I \times R}$$

Voltage
[Volt]

Current
[Amp]

Resistance
[Ohm, Ω]



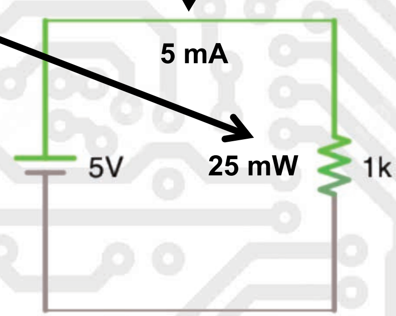
Power

$$\boxed{P = I \times V}$$

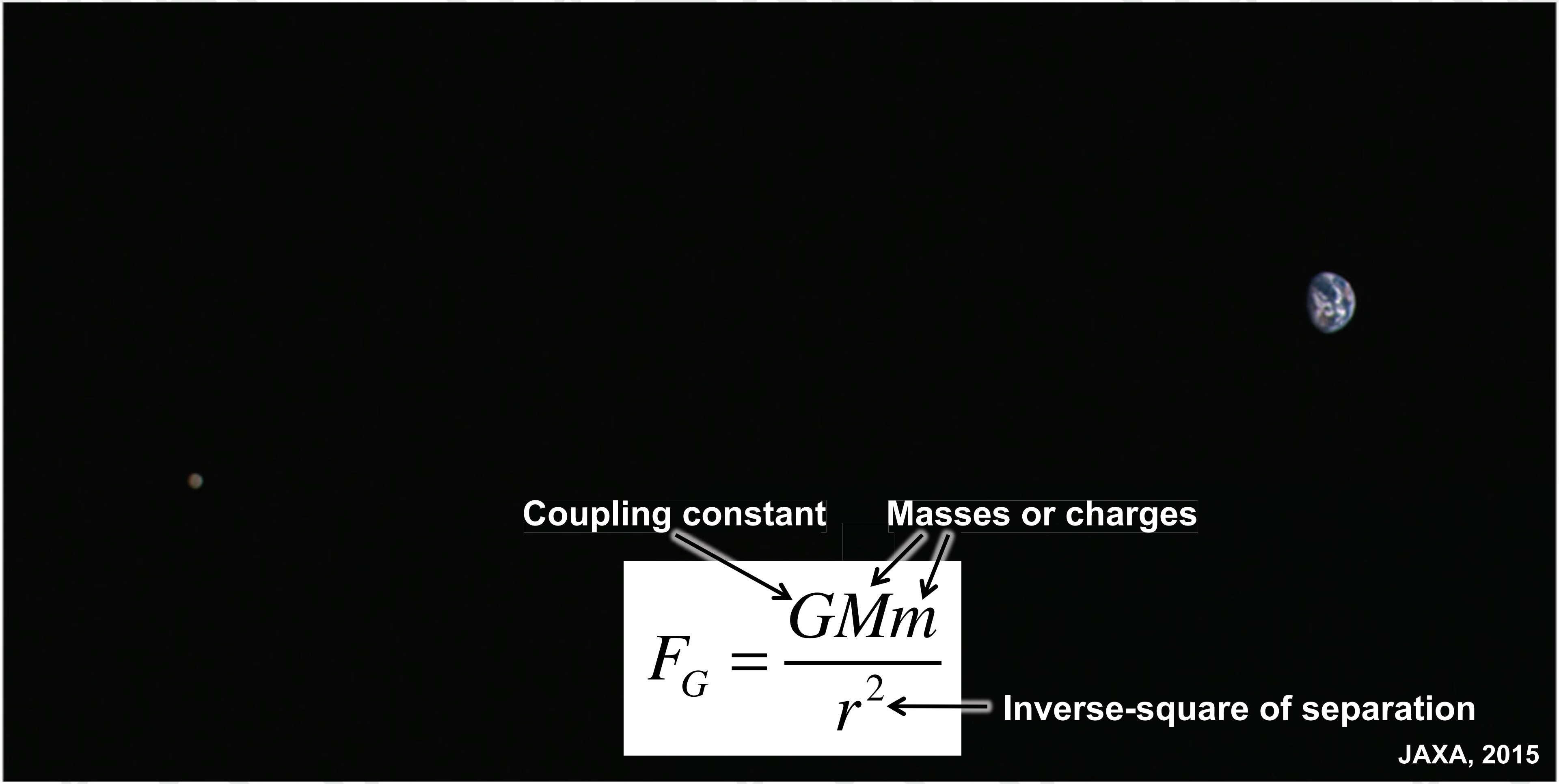
Power
[Watt]

Current
[Amp]

Voltage
[Volt]

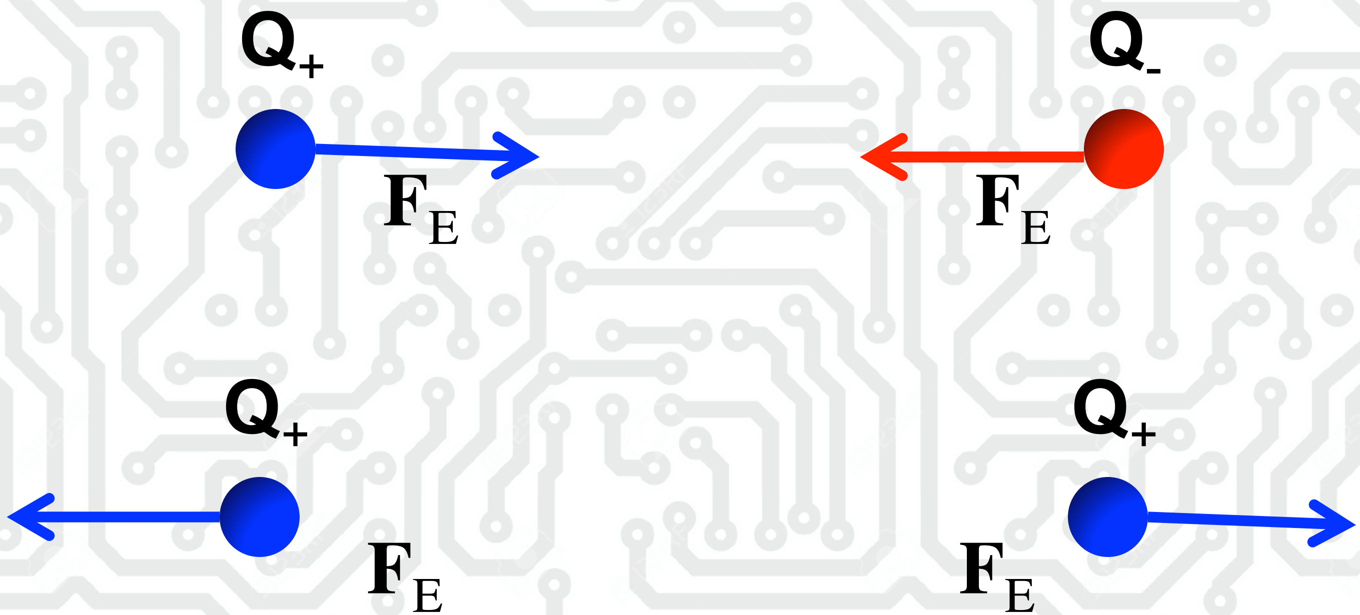


The Gravitational Force



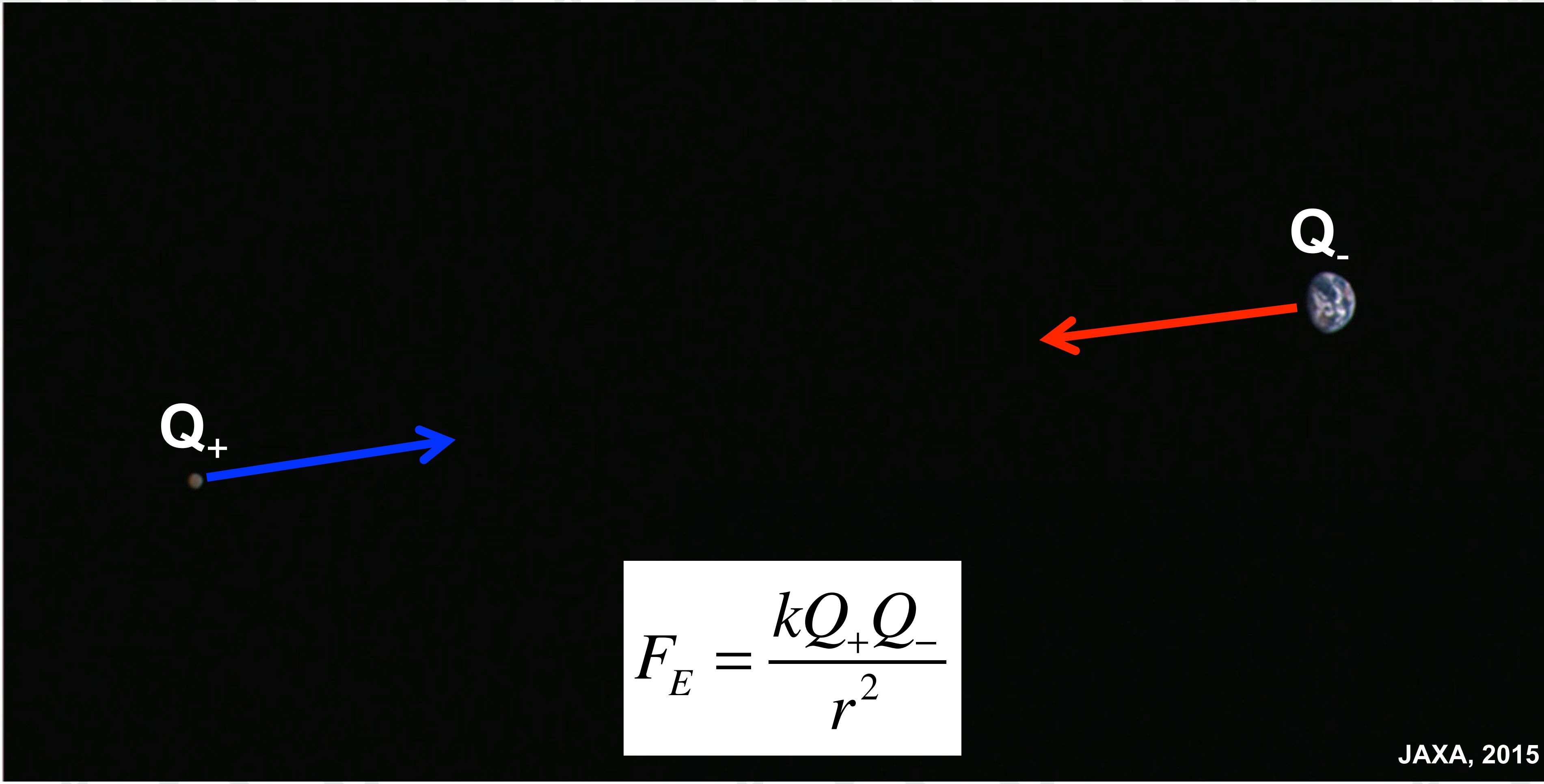
$$F_G = \frac{GMm}{r^2}$$

The Electrostatic Force



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

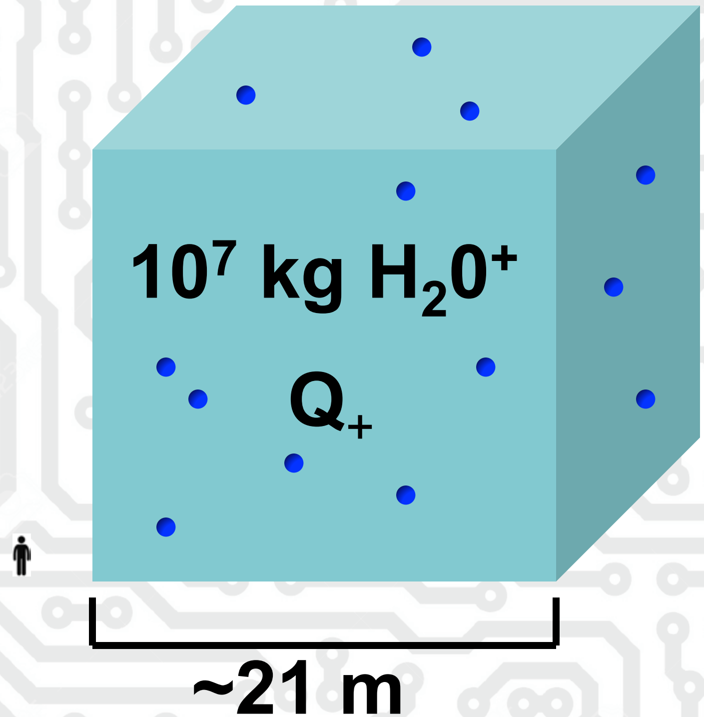
How much charge would it take to replicate the gravitational force between the Earth and Moon?

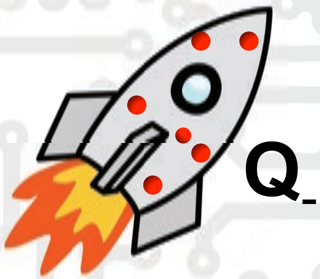


$$F_E = \frac{kQ_+Q_-}{r^2}$$

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?

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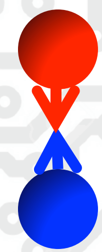
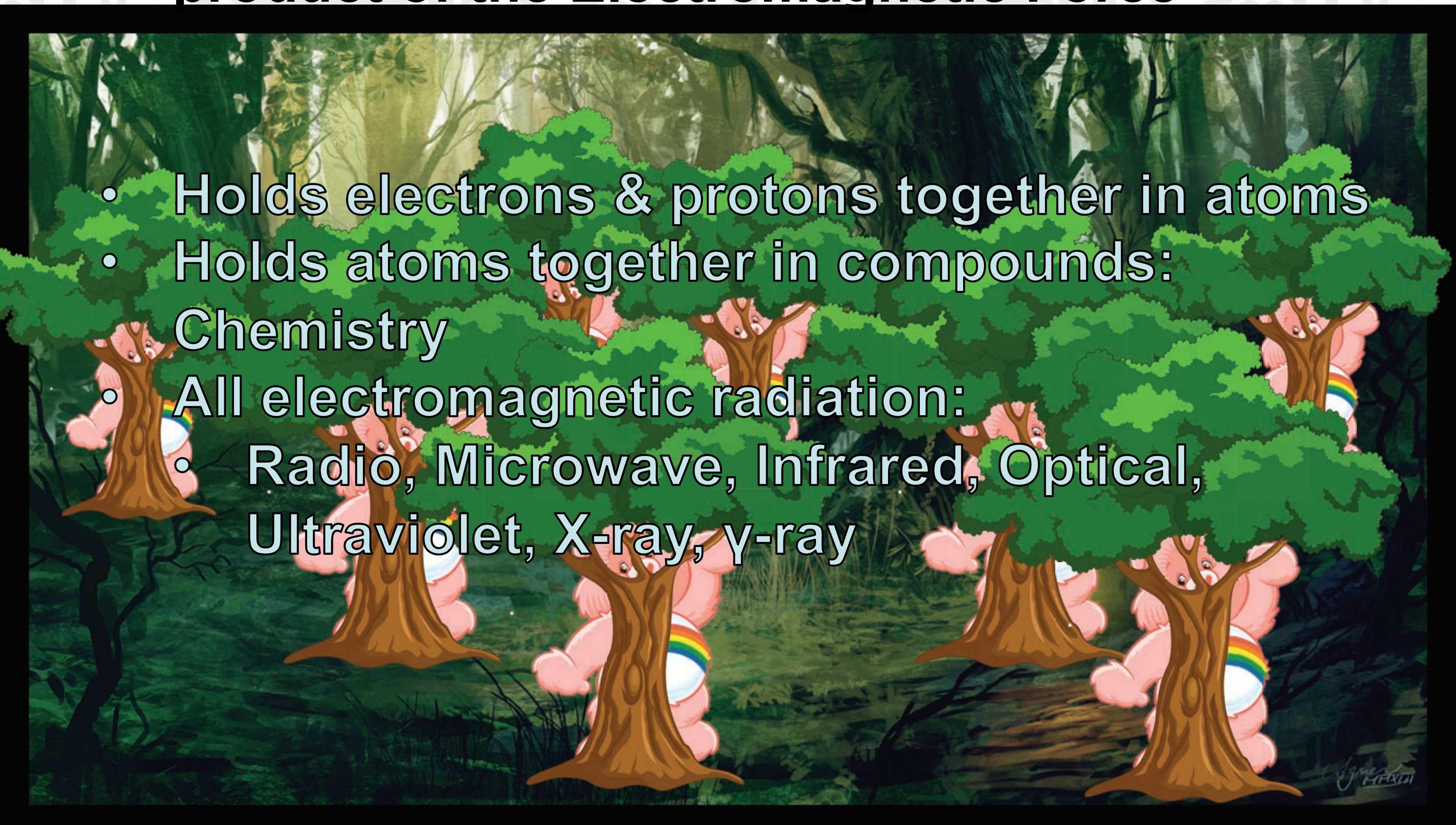
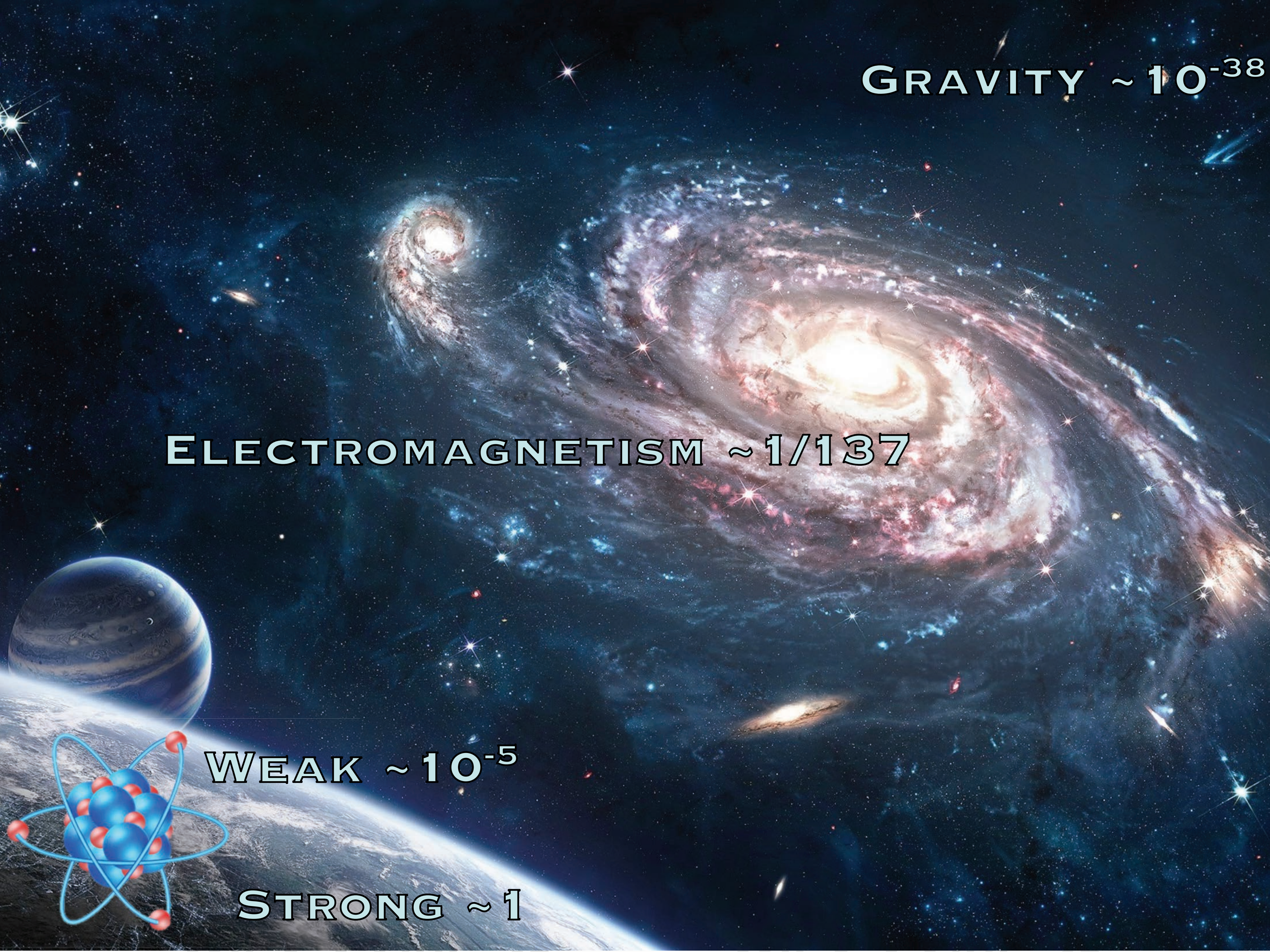


It is!

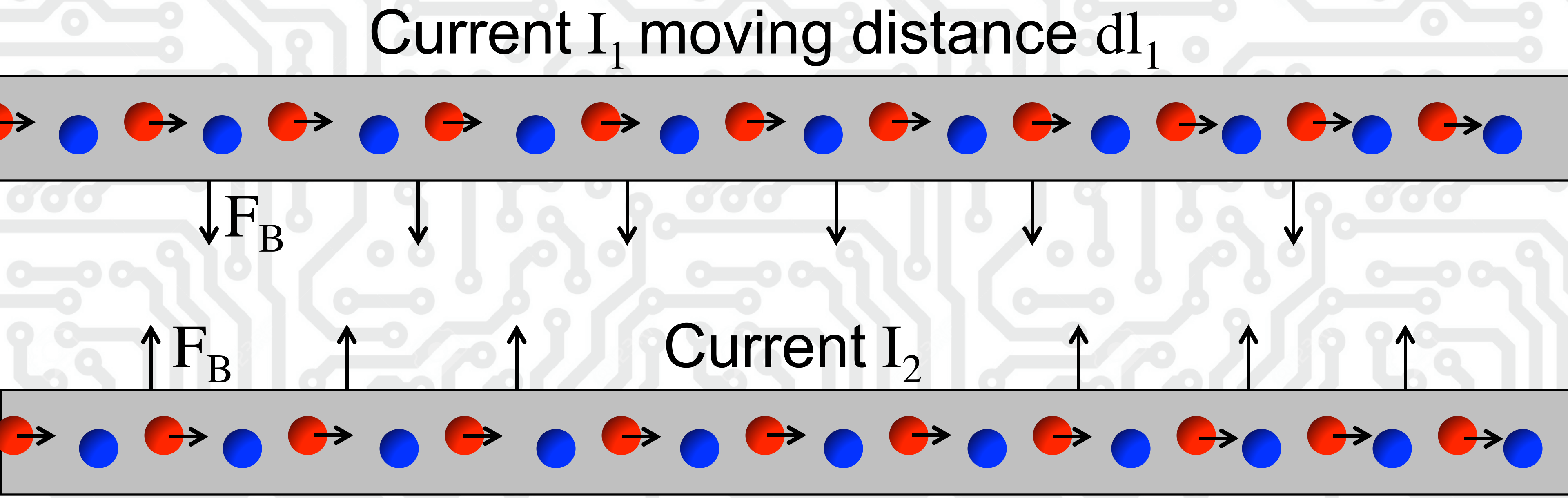
Virtually everything in our experience is a product of the Electromagnetic Force



- 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 ~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, •, 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

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

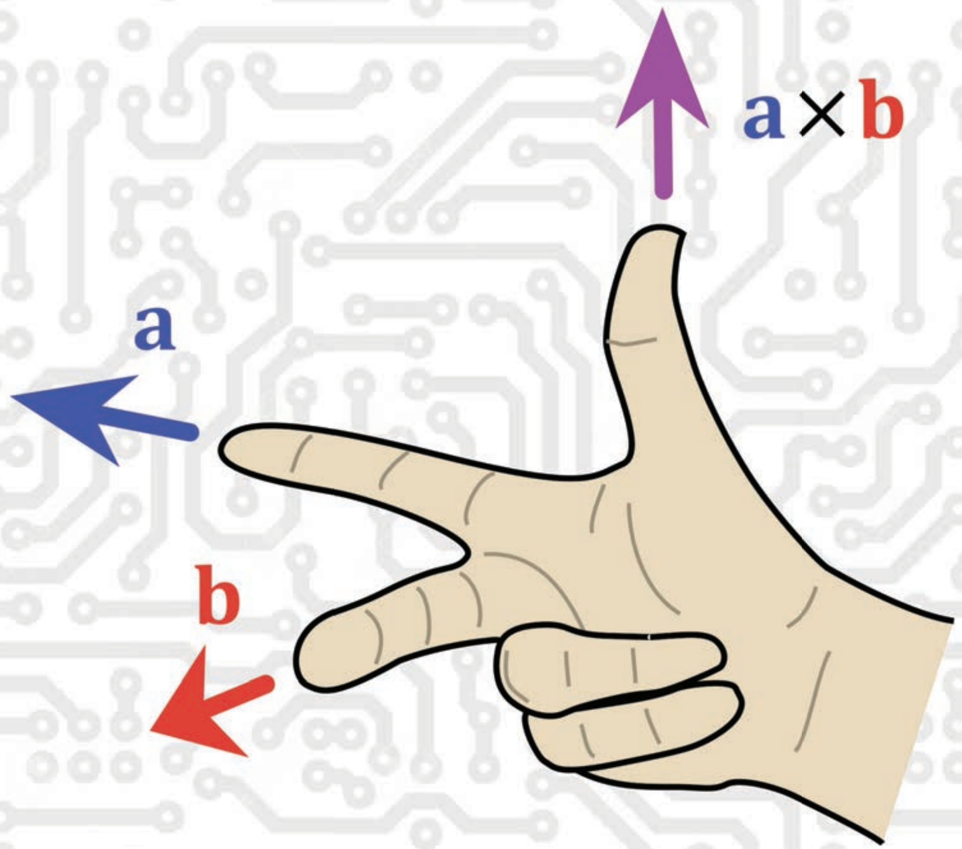
Biot-Savart Law **tells how currents create B-fields**

$$F_B = I_2 dl_2 \times B$$

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

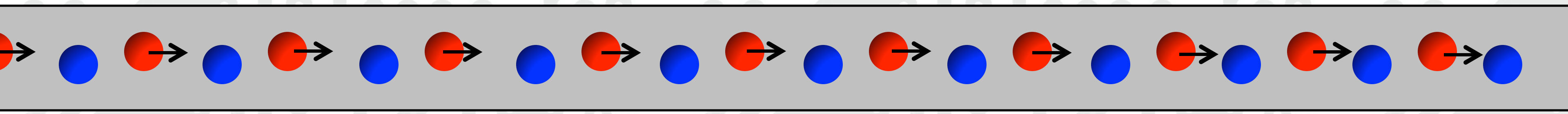
We have replaced the dot, $\bullet$, that meant parallel currents attract, with two $\times$'s. These are cross-products.

The Right-Hand Rule



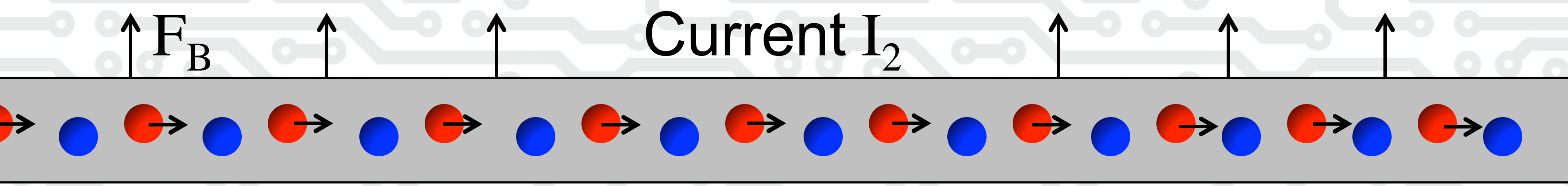
The Magnetic Force

Current I_1 moving distance dl_1

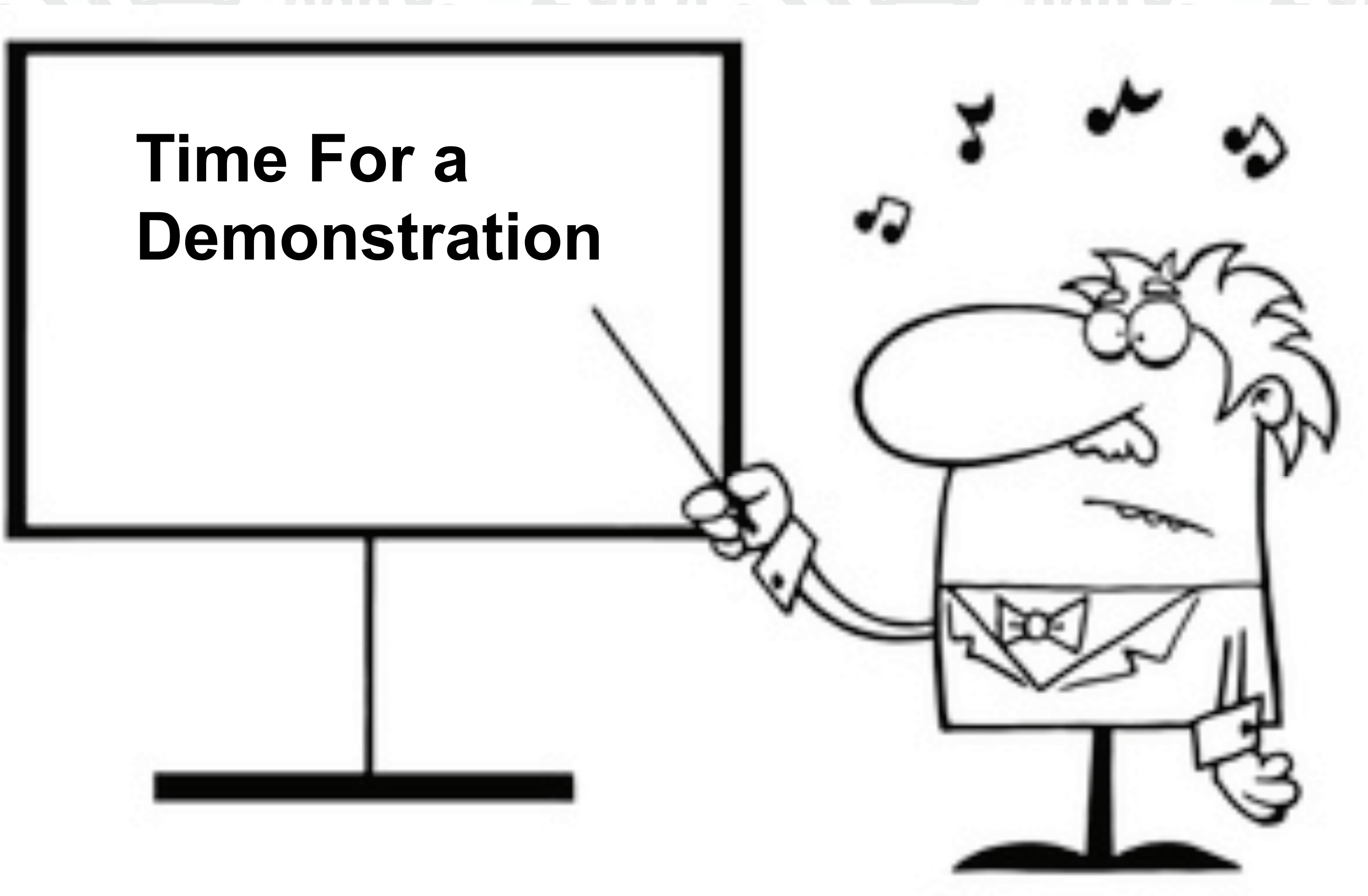


Biot-Savart: B ~ $dl_1 \times r$ is into the screen

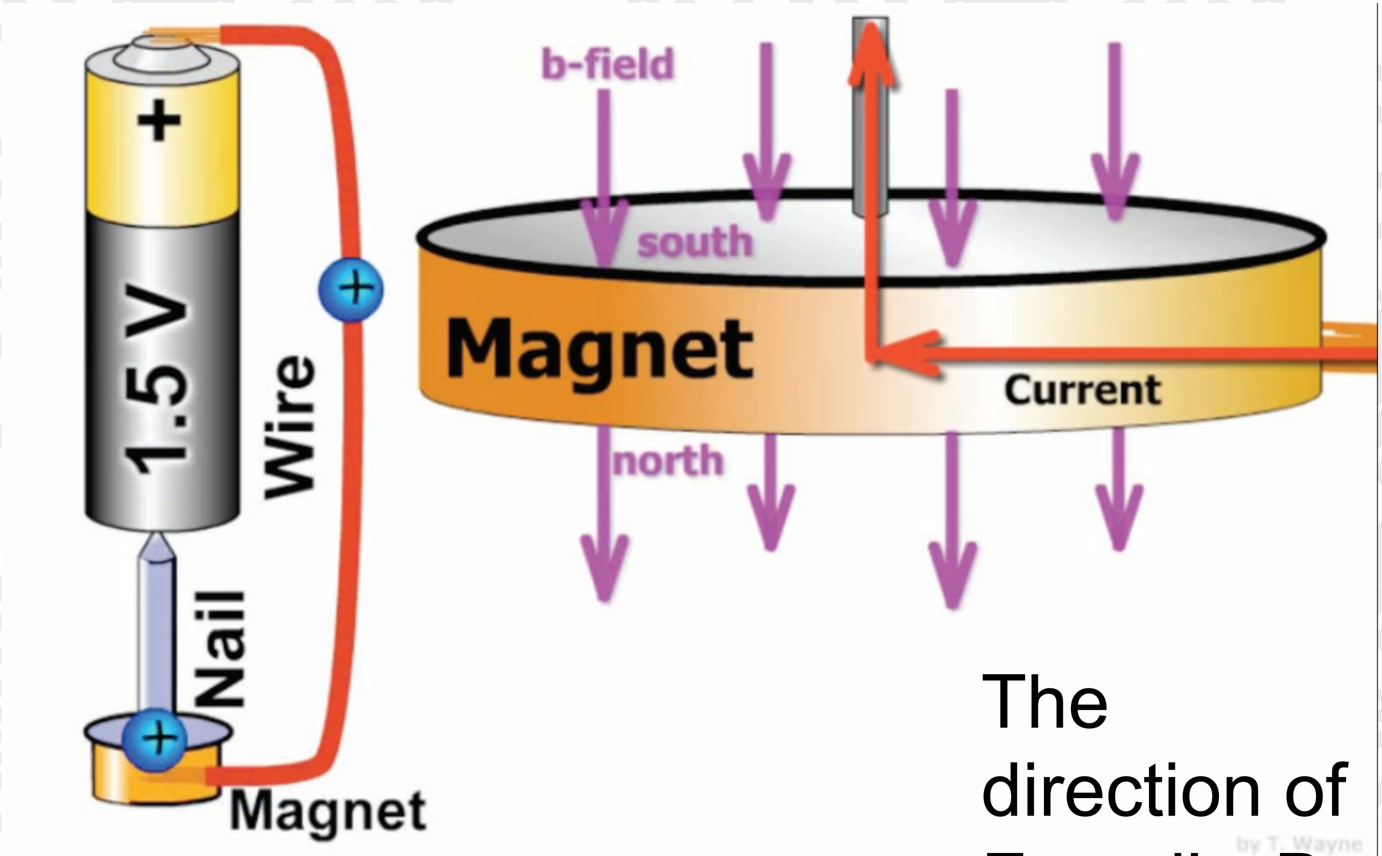
Lorentz Force: F_B ~ $dl_2 \times B$ is upward



This two-step process gives the same answer.


Time For a
Demonstration

The Homopolar Motor



The direction of $F_B \sim dI_2 \times B$ is?

By the Numbers

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

Mass $M = \rho V = 2\pi\rho R^2 H \approx 9.7$ gm

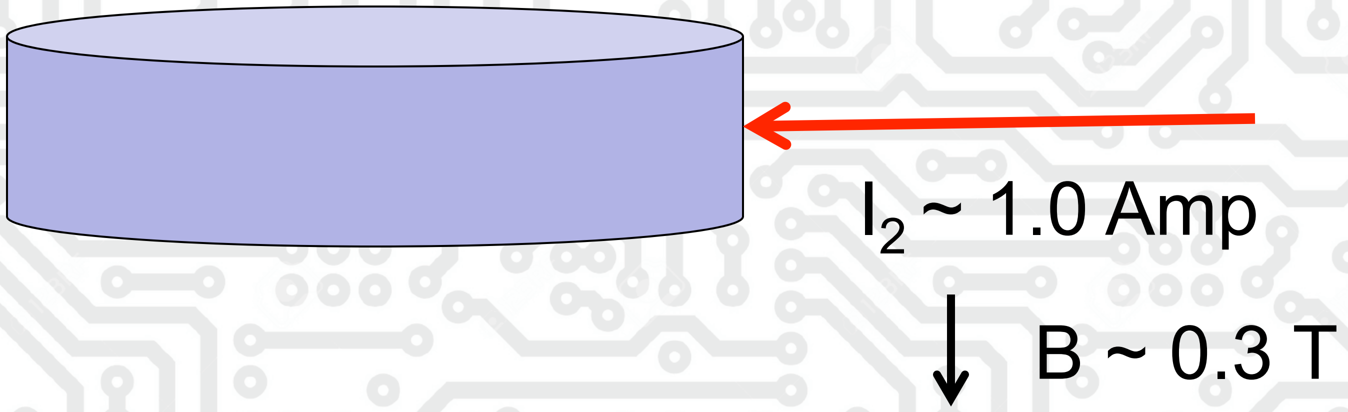
Moment of Inertia $I = \frac{1}{2} M R^2 = 1.8 \times 10^{-7}$ kg-m

By the Numbers

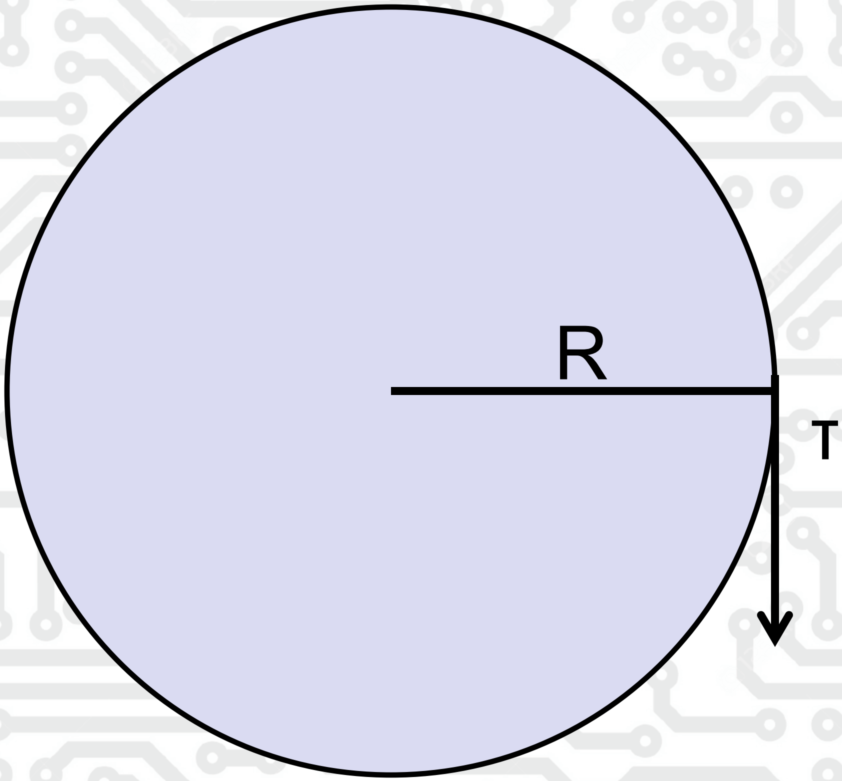
$F_B \sim I_2\, dl_2\, B =$
6×10^{-4} Newtons

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

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:

$\tau = I\omega'$

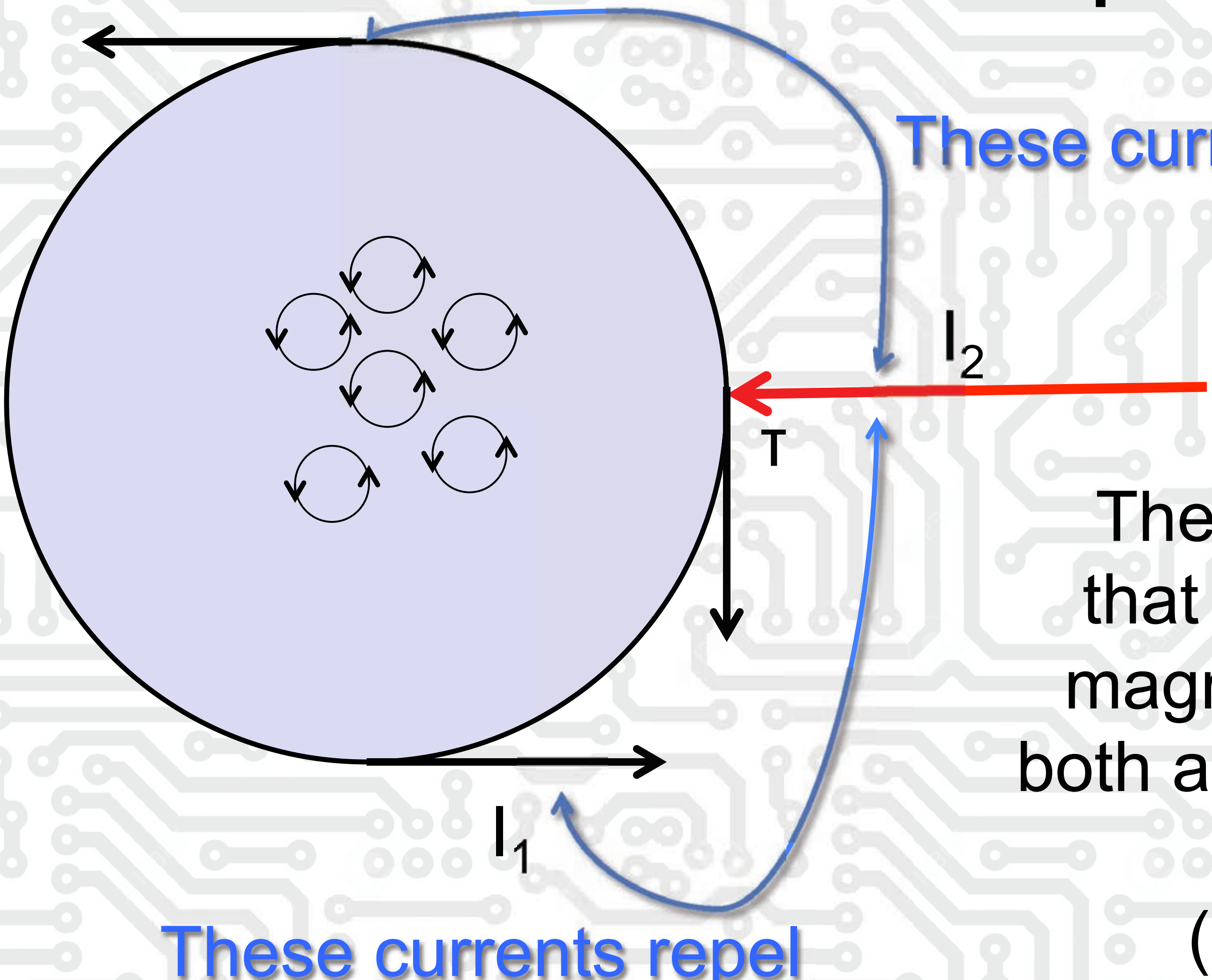
So

$\omega' = \tau/I \approx 20\ s^{-2}$

$f' = \omega'/2\pi \approx 3\ s^{-2}$
$= 3$ Hz / s

So in about 1 second the disk speeds up to a frequency of <u>~ 3 Hz</u>
A reasonable number.

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