Happy 12th Birthday Arduino!

LAS POSITAS COLLEGE

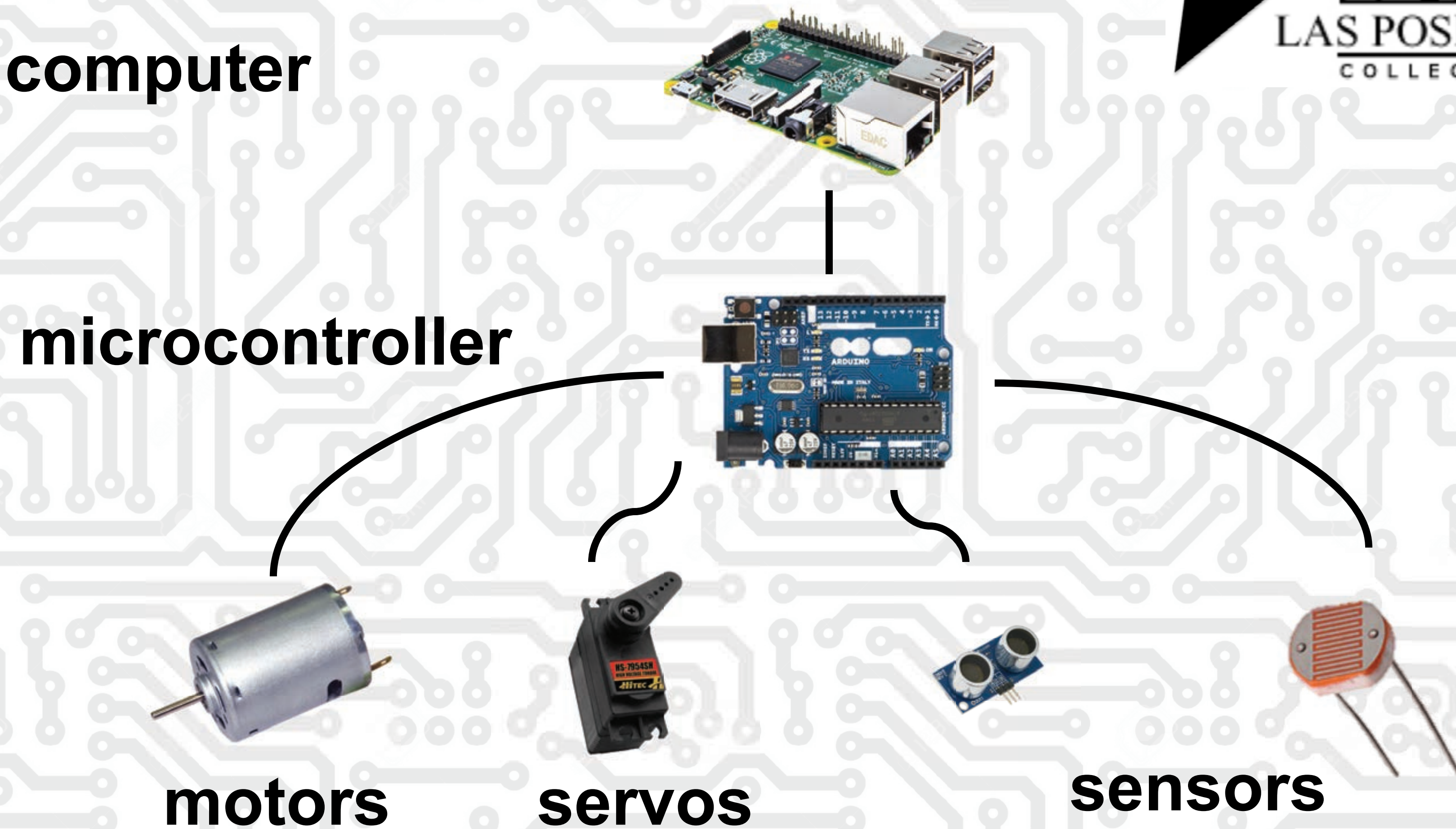
ARDUINO DAY 2016

Saturday, April 2 at Robot Garden, 11AM to 3PM

Robot Garden

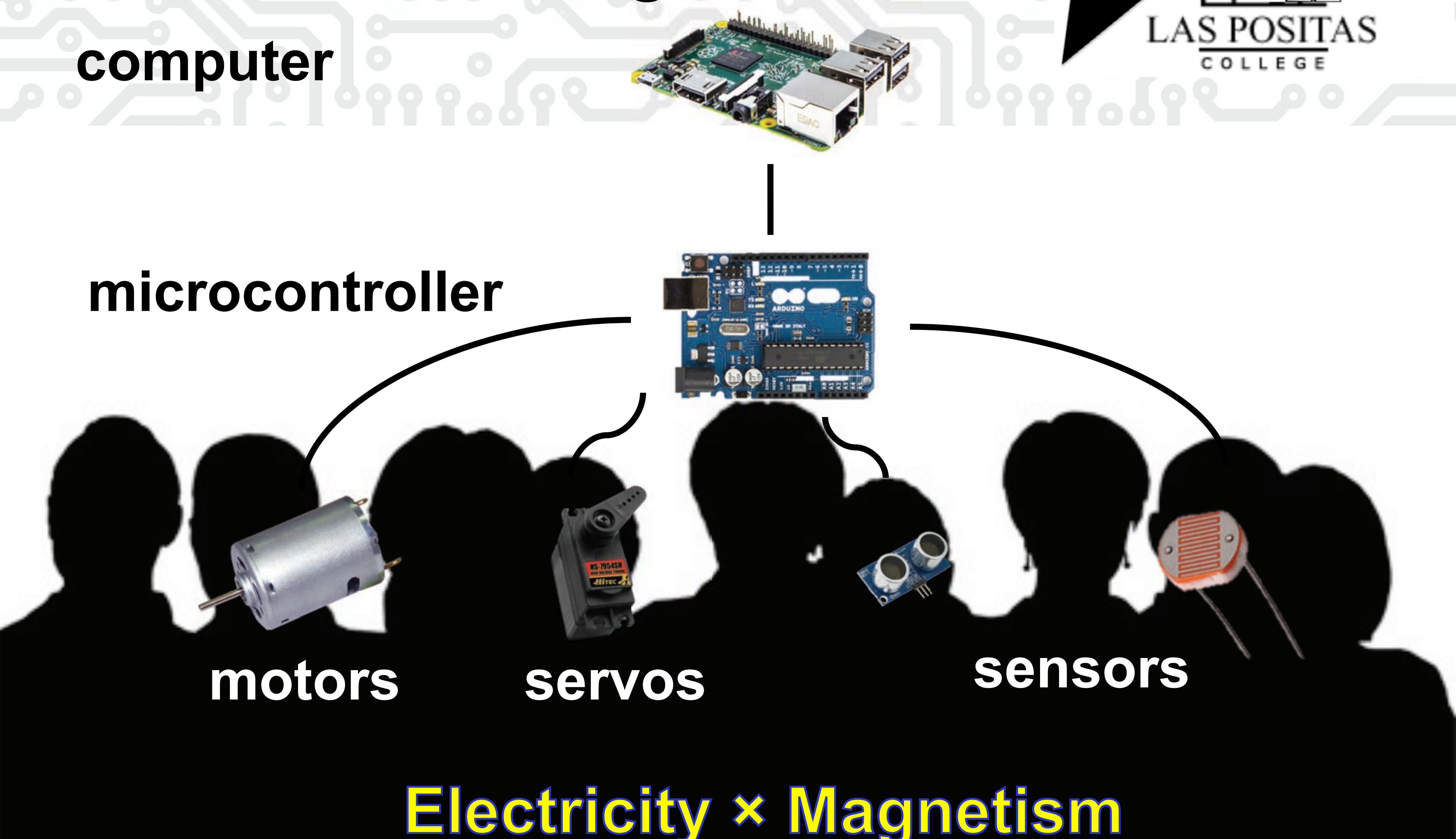
day.arduino.cc

The Maker-verse



Electricity × Magnetism

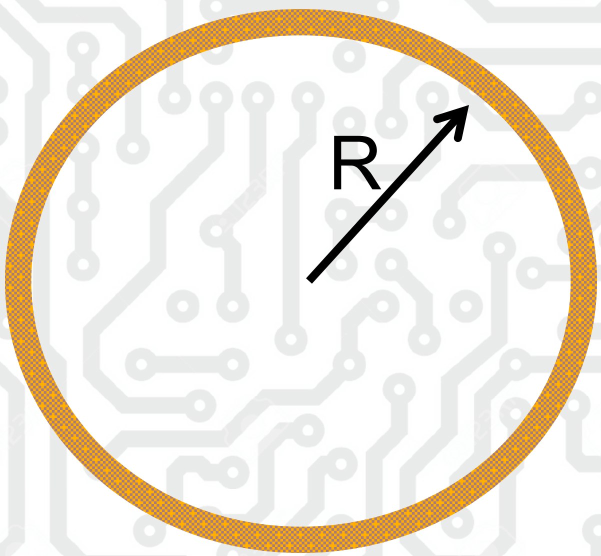
The Maker-verse plus a Village



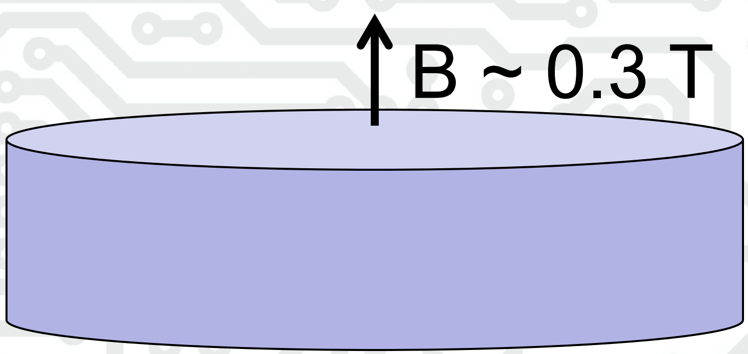
Review

- 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

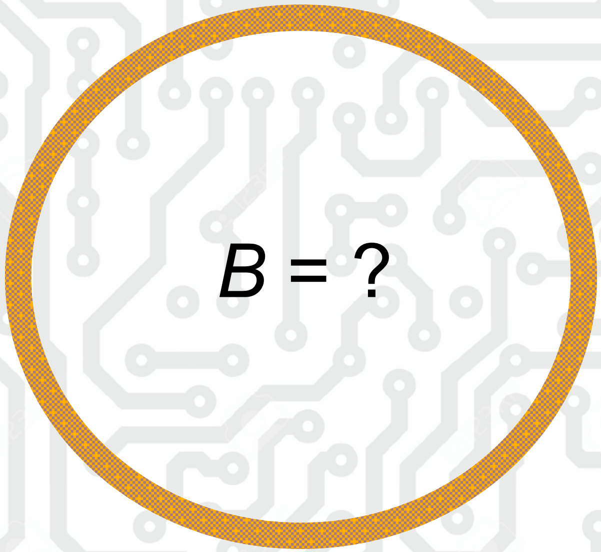
Simple Motor



Wire loop:
N ~ 10 loops
R = 7.5 mm = 7.5 × 10^{-3} m
M ~ 0.5 gram
I ~ 4 Amps



What is the field generated by this loop?



We need the *Biot-Savart Law* to find out:

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

$$B \sim \frac{\mu_0}{4\pi}\frac{I_1 2\pi R}{R^2} = \frac{\mu_0 I_1}{2R}$$

This turns out to be the exact answer

$\sim \mu_0$ (4 A)/(2 × 7.5 mm) $\sim 270\ \mu_0$

So how big is μ_0?

Recall that μ_0 is the coupling constant for the magnetic force:

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

So how big is μ_0?

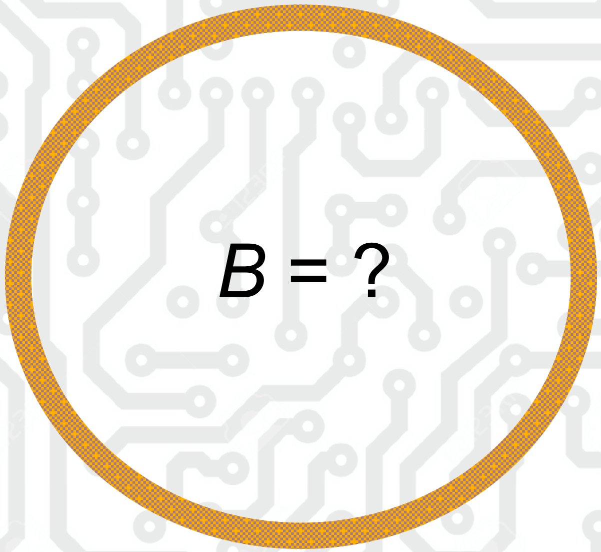
Recall that μ_0 is the coupling constant for the magnetic force (also called the permeability of free space):

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

$\mu_0 = 4\pi \times 10^{-7}$ T m / A

That's a small number!

What is the field generated by this loop?



We need the *Biot-Savart Law* to find out:

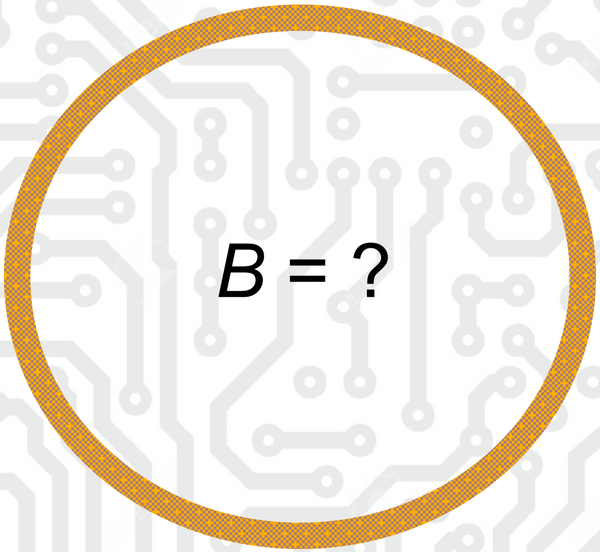
$$B = \frac{\mu_0}{4\pi}\frac{I_1 dl_1 \times \hat{r}}{r^2}$$

$$B \sim \frac{\mu_0}{4\pi}\frac{I_1 2\pi R}{R^2} = \frac{\mu_0 I_1}{2R} \longleftarrow$$

This turns out to be the exact answer

B ~ μ_0 (4 A)/(2 × 7.5 mm) ~ 270 μ_0
~ 3 × 10^{-5} T = 0.3 Gauss

What can we do about this?

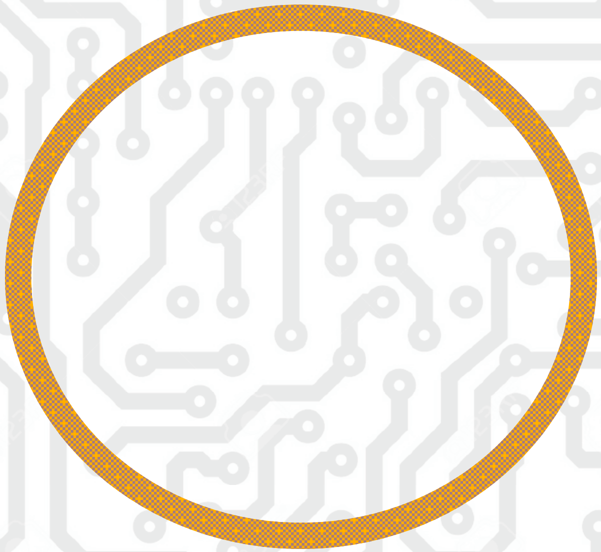


$B \sim 3 \times 10^{-5}$ T = 0.3 Gauss
similar to that of the Earth

This is much smaller than the 0.3 T from our magnet. One trick we can play is wind the current around the loop N times, multiplying the field by N. If N=10:

$$B \sim 3 \text{ G} = 3 \times 10^{-4} \text{ T}$$

Simple Motor

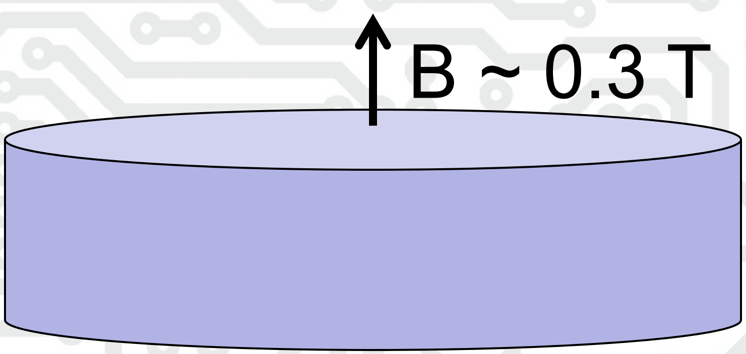


Magnetic moment of the wire loop:

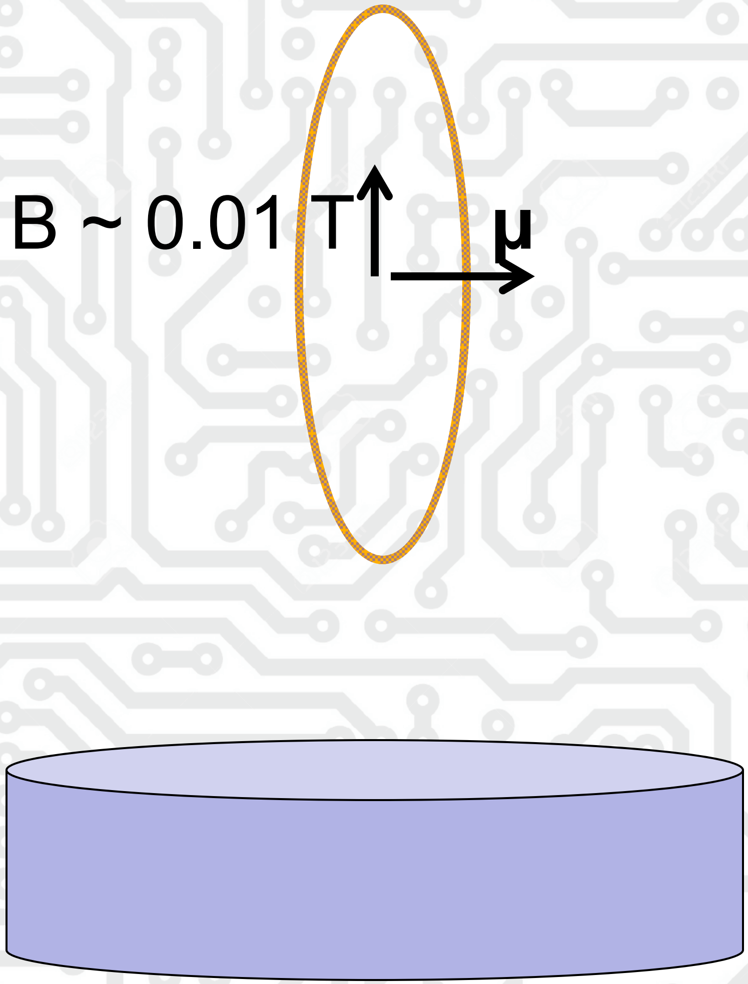
$\mu_m = N\,I\,A$

$\sim 10 * (4\text{ A}) * (\pi\,(7.5\text{e-}3\text{ m})^2)$

$\sim 7 \times 10^{-3}\text{ A m}^2$



Simple Motor

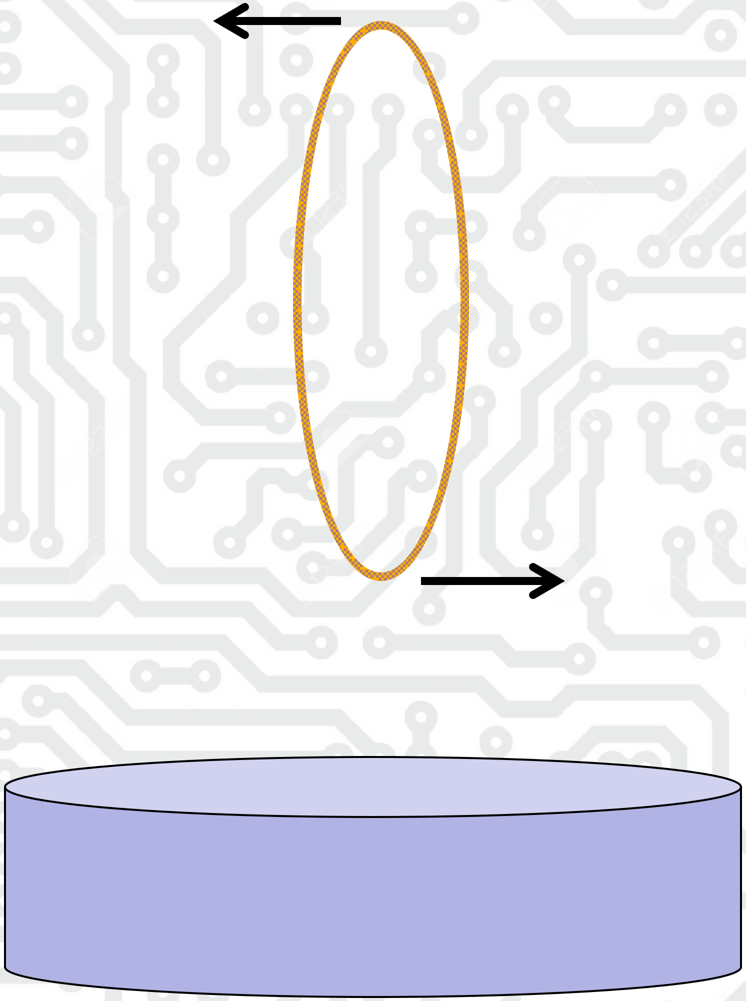


Max Torque $\tau_{mx} = \mu_m \times B$
$\sim 7 \times 10^{-5}$ N m

But no torque over remainder of rotation, so average torque:
$\tau \sim \tau_{mx} / 10 \sim 10^{-5}$ N m

Similar to the torque on the homopolar motor

Simple Motor



Max Torque $\tau_{mx} = \mu_m \times B$

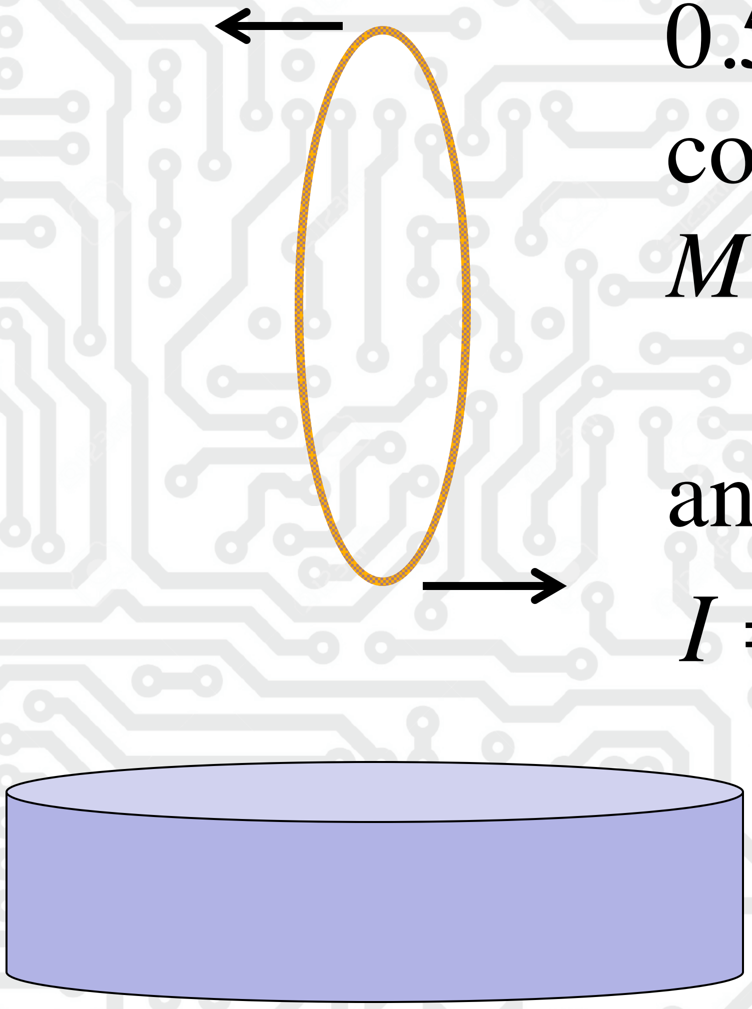
$\sim\ 7 \times 10^{-5}$ N m

But no torque over remainder of rotation, so average torque:

$\tau \sim \tau_{mx} / 10 \sim 7 \times 10^{-6}$ N m

Similar to the torque on the homopolar motor

Simple Motor



0.5 m of 26 gauge copper wire has a mass:

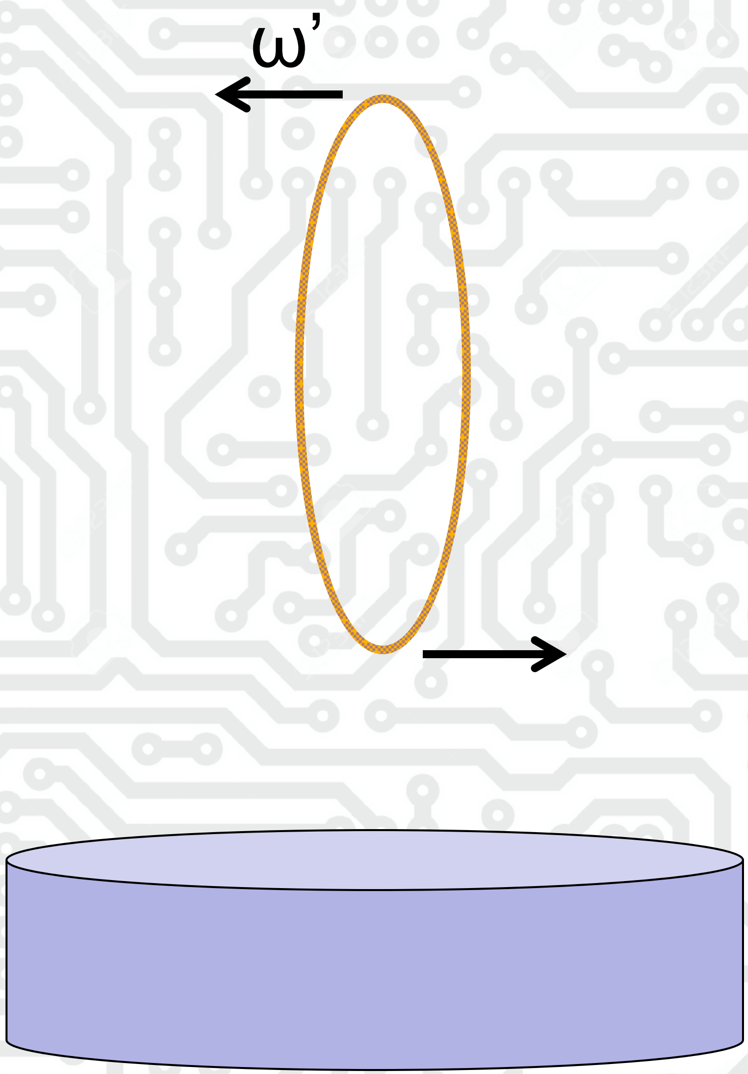
$M \sim 0.5 \times 10^{-3}\ kg$

and a moment of inertia:

$I = \frac{1}{2} MR^2 \sim 1.5 \times 10^{-8}$

This wire ring is much lighter than the magnet in the homopolar motor

Simple Motor



Newton’s force law for rotation:

$\tau = I\omega'$

So

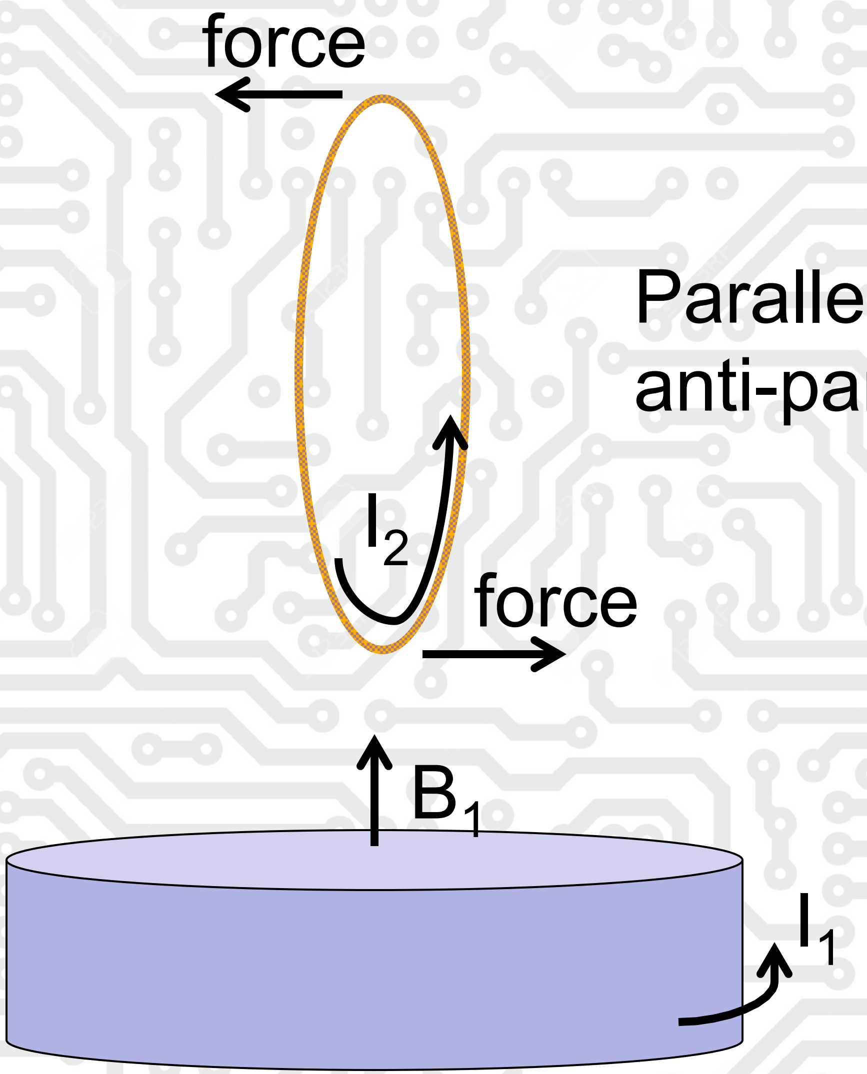
$\omega' = \tau/I \approx 500\ s^{-2}$

$f' = \omega'/2\pi \approx 75\ s^{-2}$

$= 75\ Hz\ /\ s$

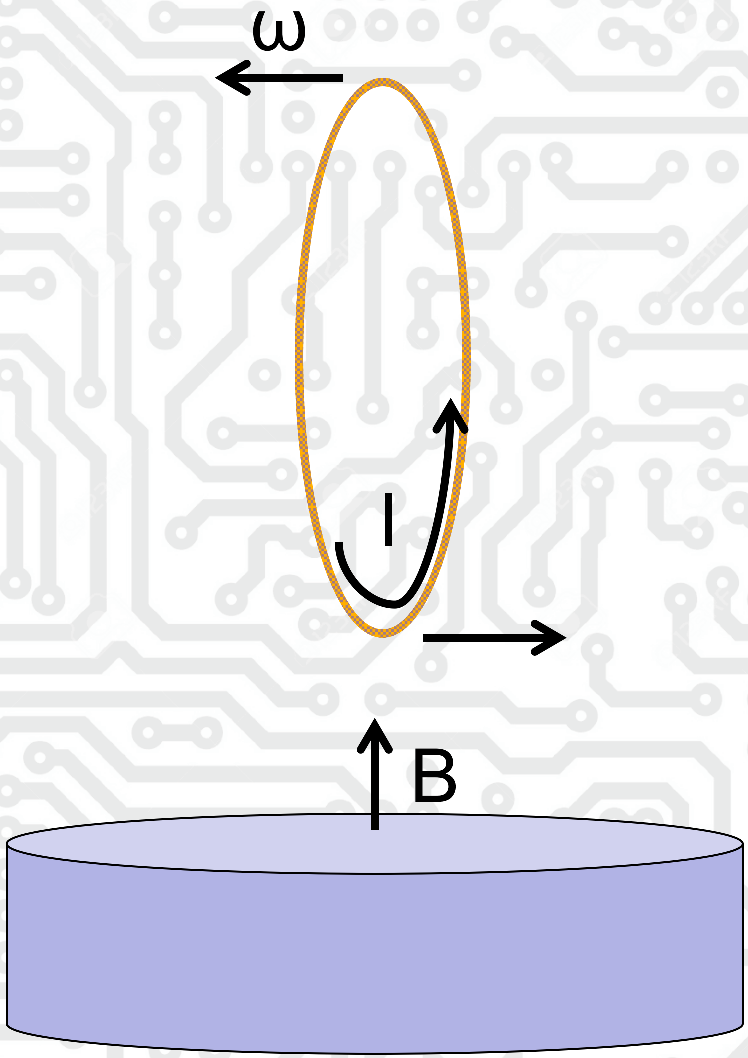
This is a large acceleration due to the small mass of the wire.

The Current Picture



Parallel current attract,
anti-parallel currents repel

Back EMF



The motion of the coil through the magnets B field (w/o a battery) induces a current in the wire…

…a so-called Back Electromotive Force … or voltage … drives this current.

Our coil pulled a large current (4 Amps) to produce a small field (3 Gauss, similar to the Earth's). Luckily it was light (0.5 gram).

How can we do anything useful with magnetic fields with such a small permeability of free space?

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\ m / A}$$

Relative permeability of materials

Material	μ / μ_0 (relative permeability)
Iron	200,000
Nickel or Carbon Steel	100
Wood	1.00000043
Air	1.0
Copper	0.999994
Superconductors	0

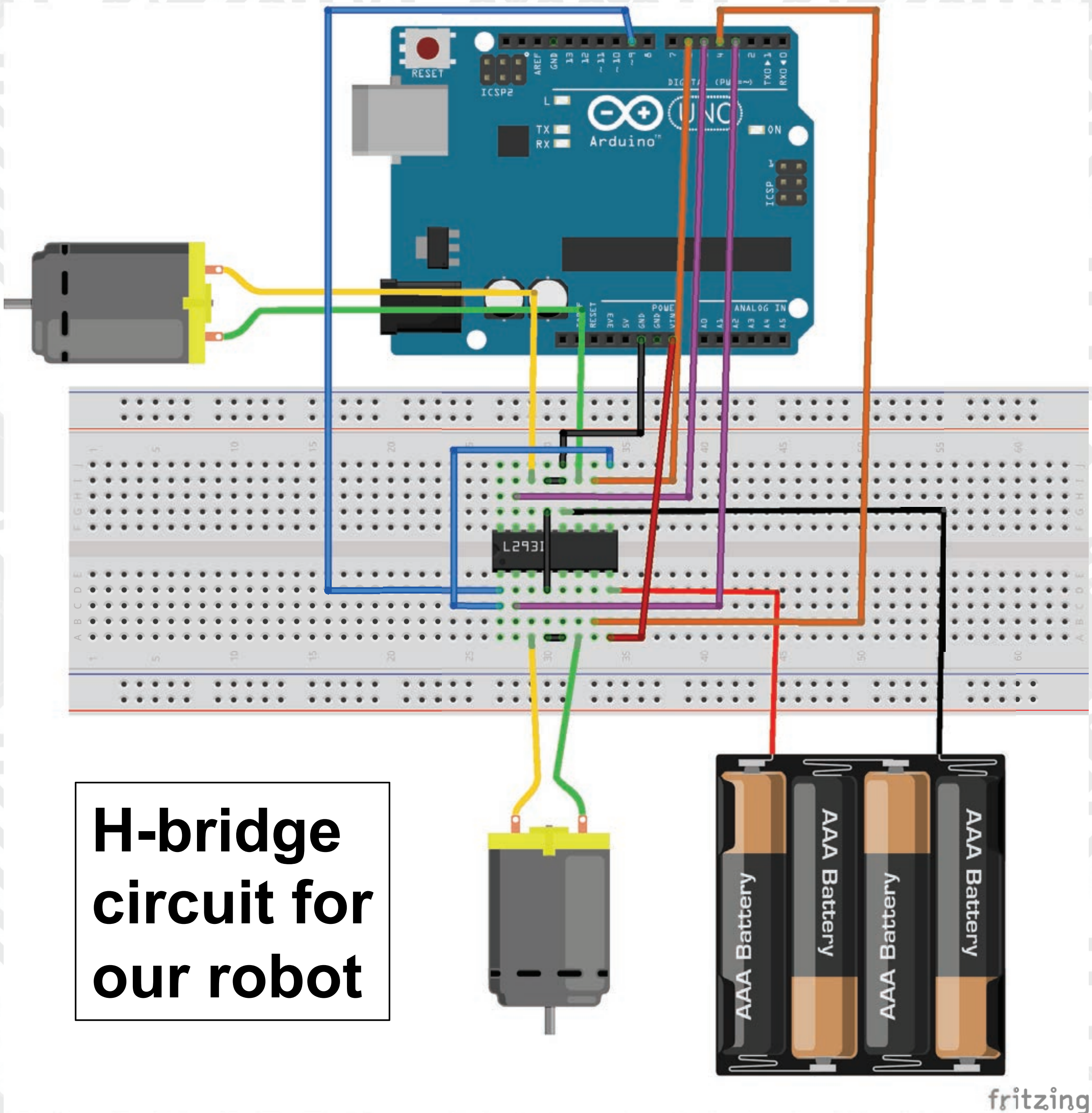
Ferromagnetic

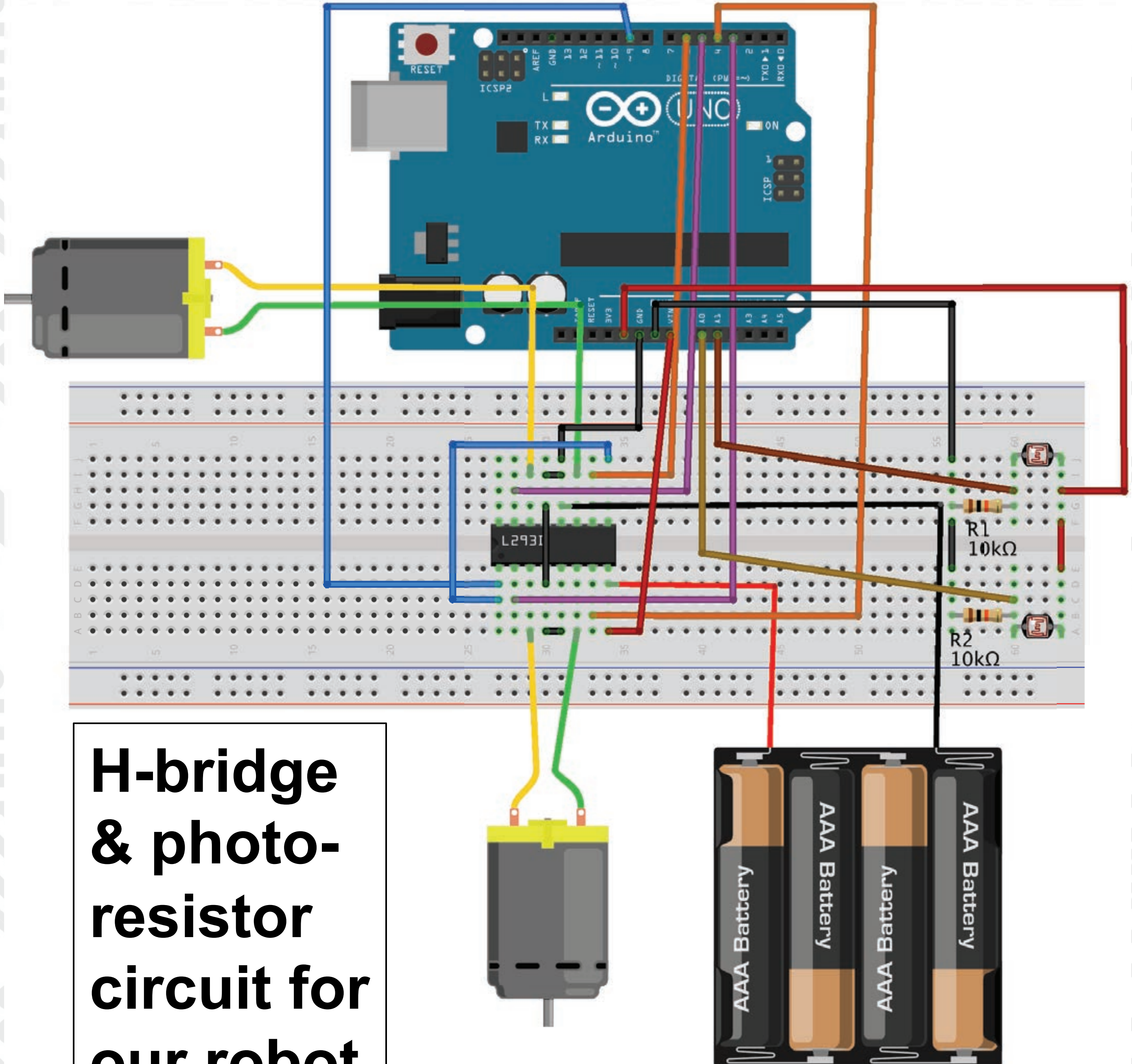
Paramagnetic

Diamagnetic

Ferromagnetism is the key that unlocks subatomic magnetism (spin) to the macro-world

H-bridge circuit for our robot





H-bridge & photo-resistor circuit for our robot

Summary

- Simple Wire Motor
  - Magnetic Field Picture
  - Current Picture
- Permeability (magnetic force constant) is small!
- Magnetic permeability of matter:
  - Diamagnetism
  - Paramagnetism
  - Ferromagnetism (a miracle!)

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})