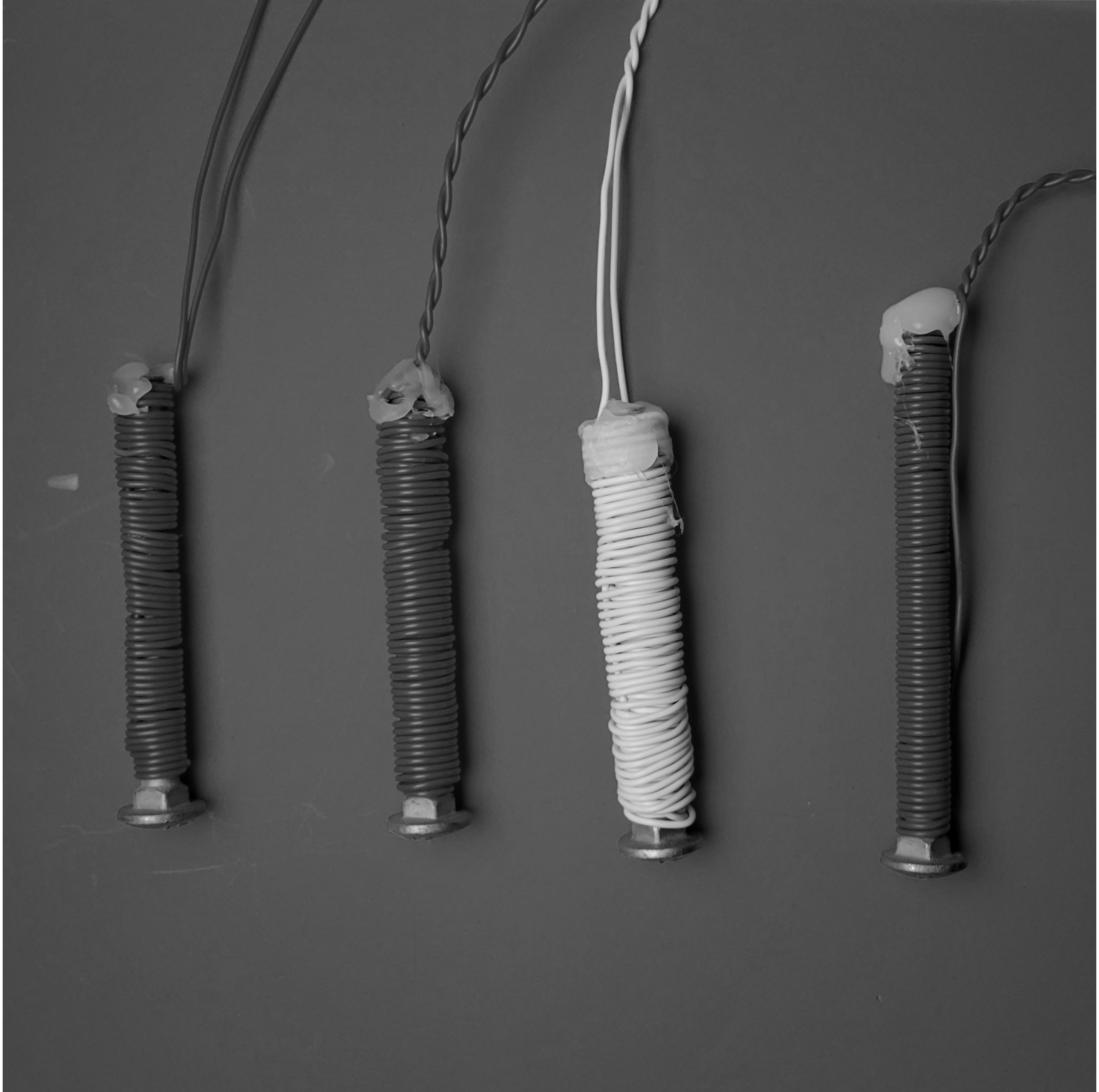
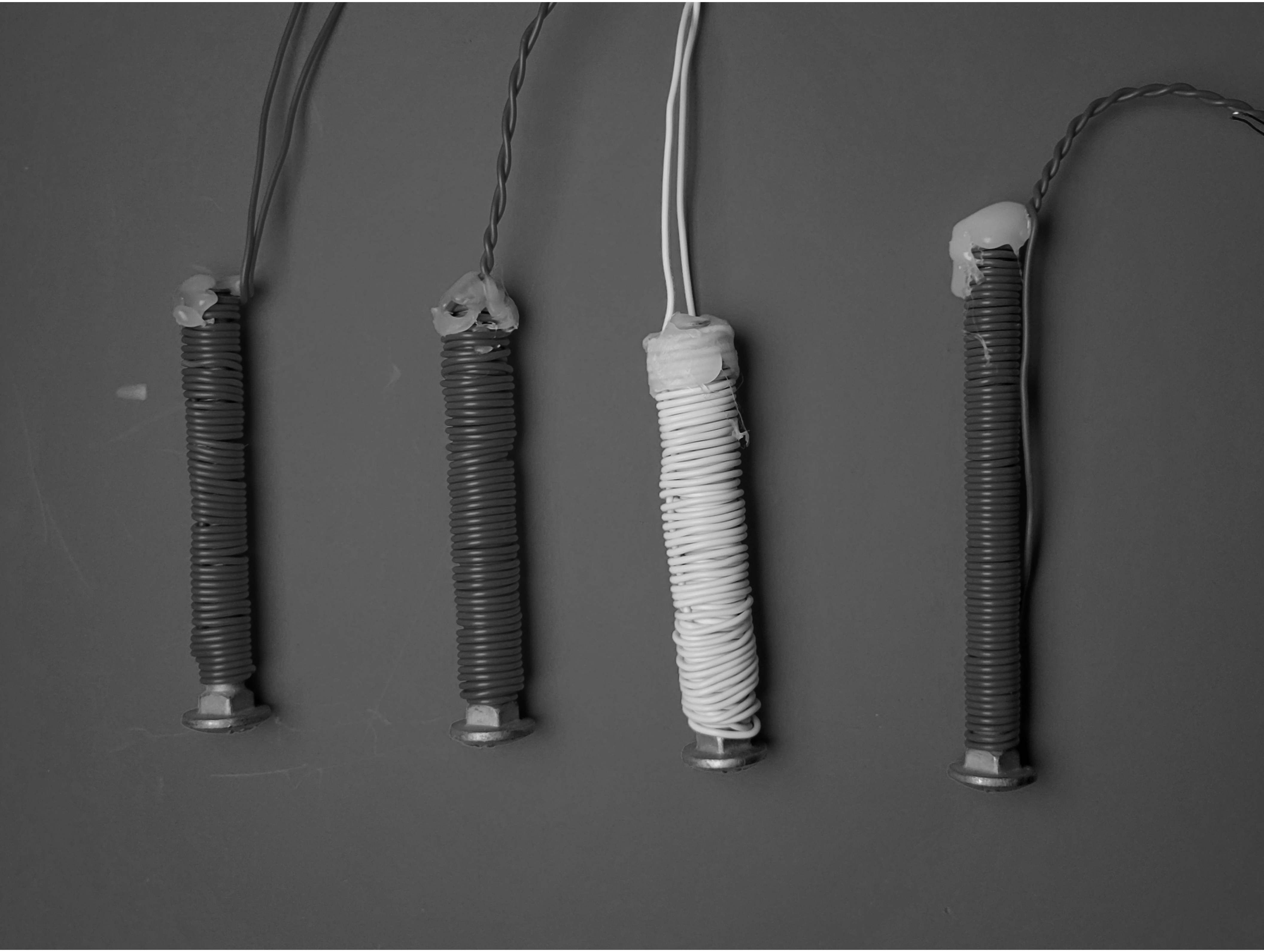
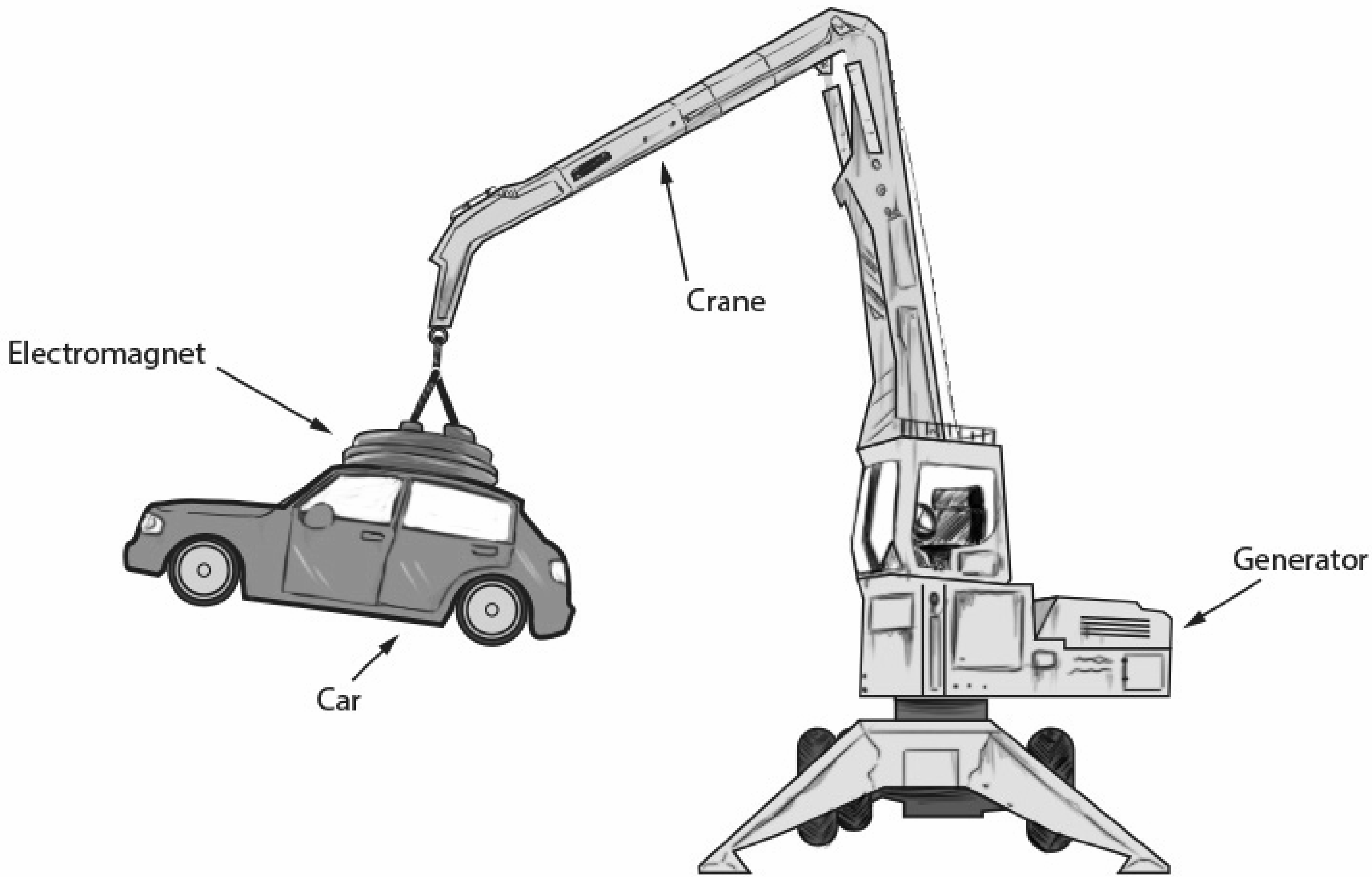
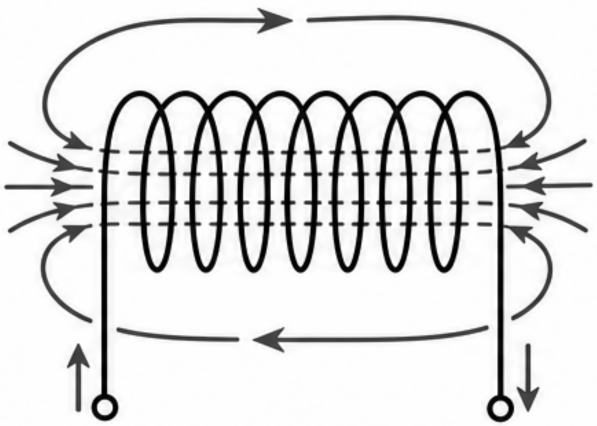

Energizer
ALKALINE BATTERY
PILE ALCALINE
6V
SIZE · FORMAT
529 · 4LR20X · 6V

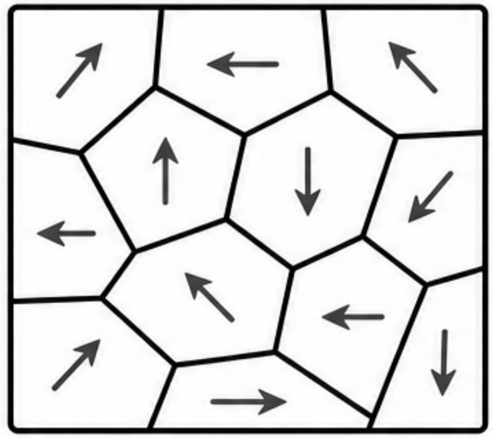




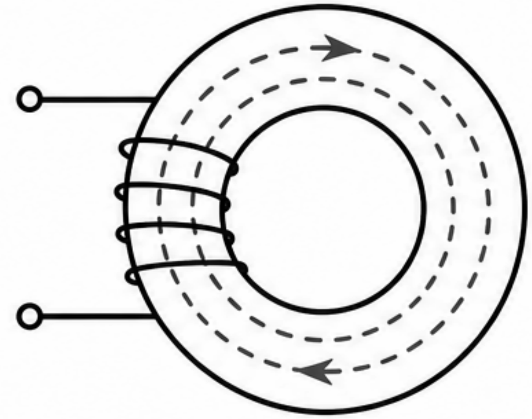

Electromagnet
Crane
Generator
Car



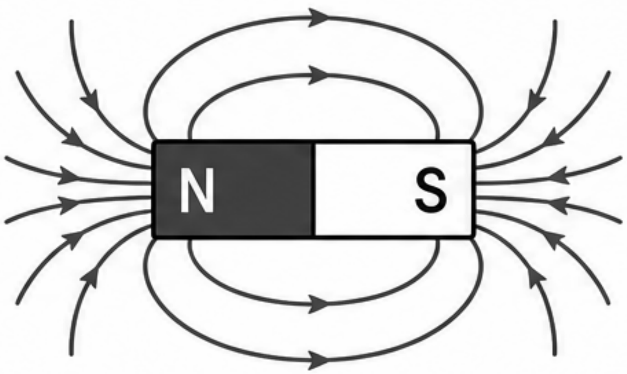
Solenoid



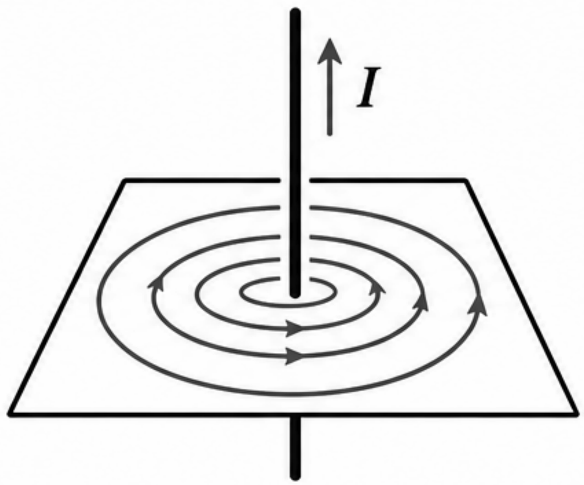
Ferromagnetism



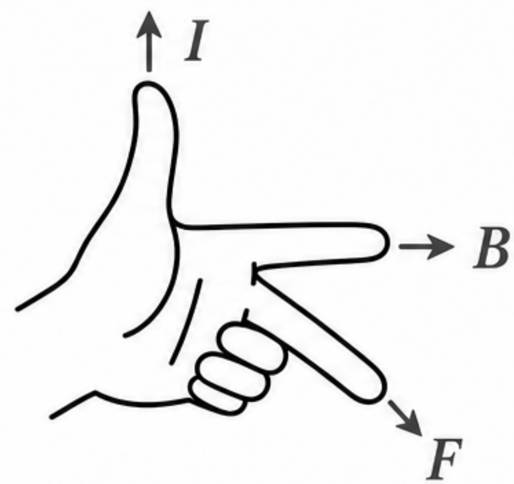
Permeability



Magnetic Flux

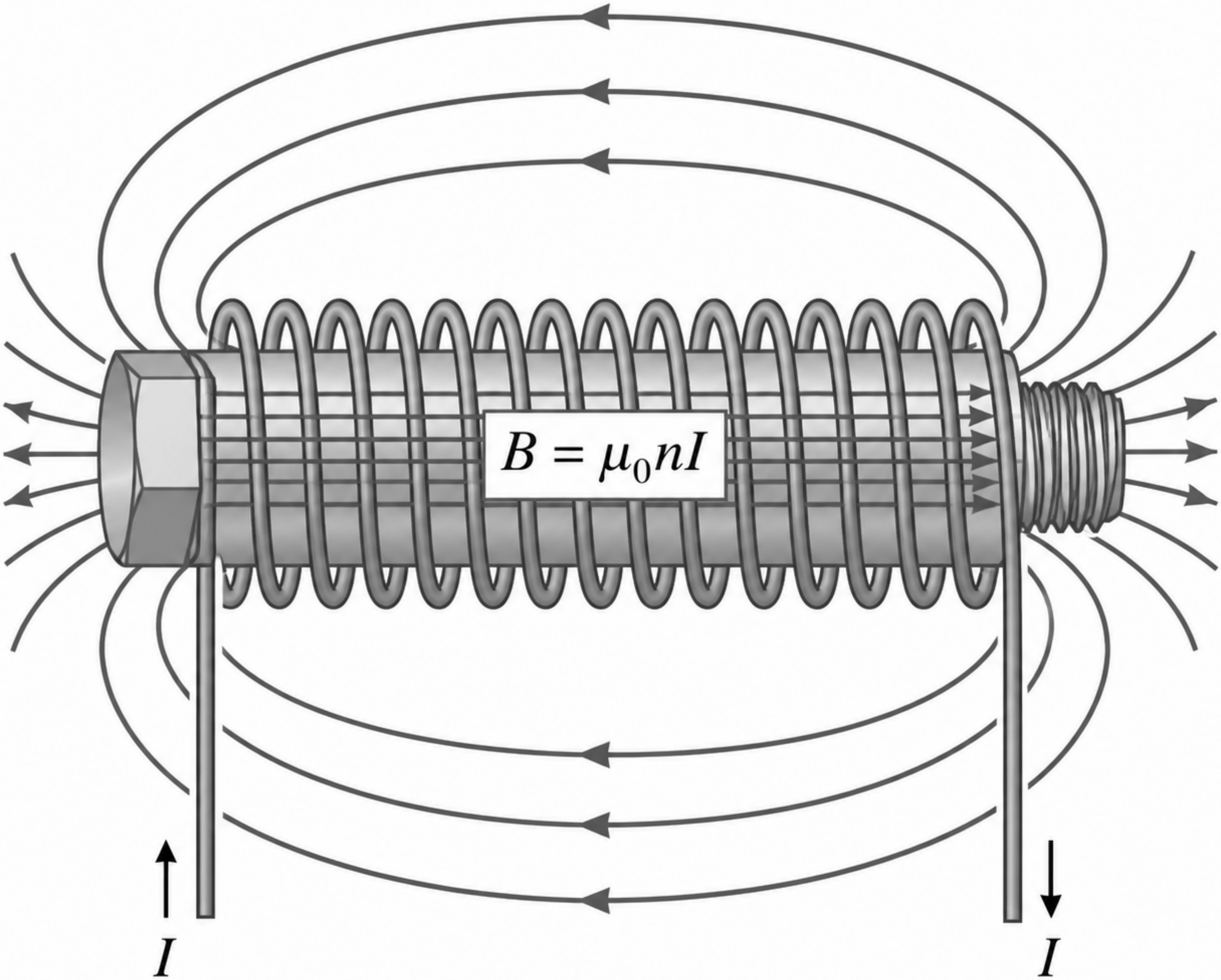


Ampere’s Law



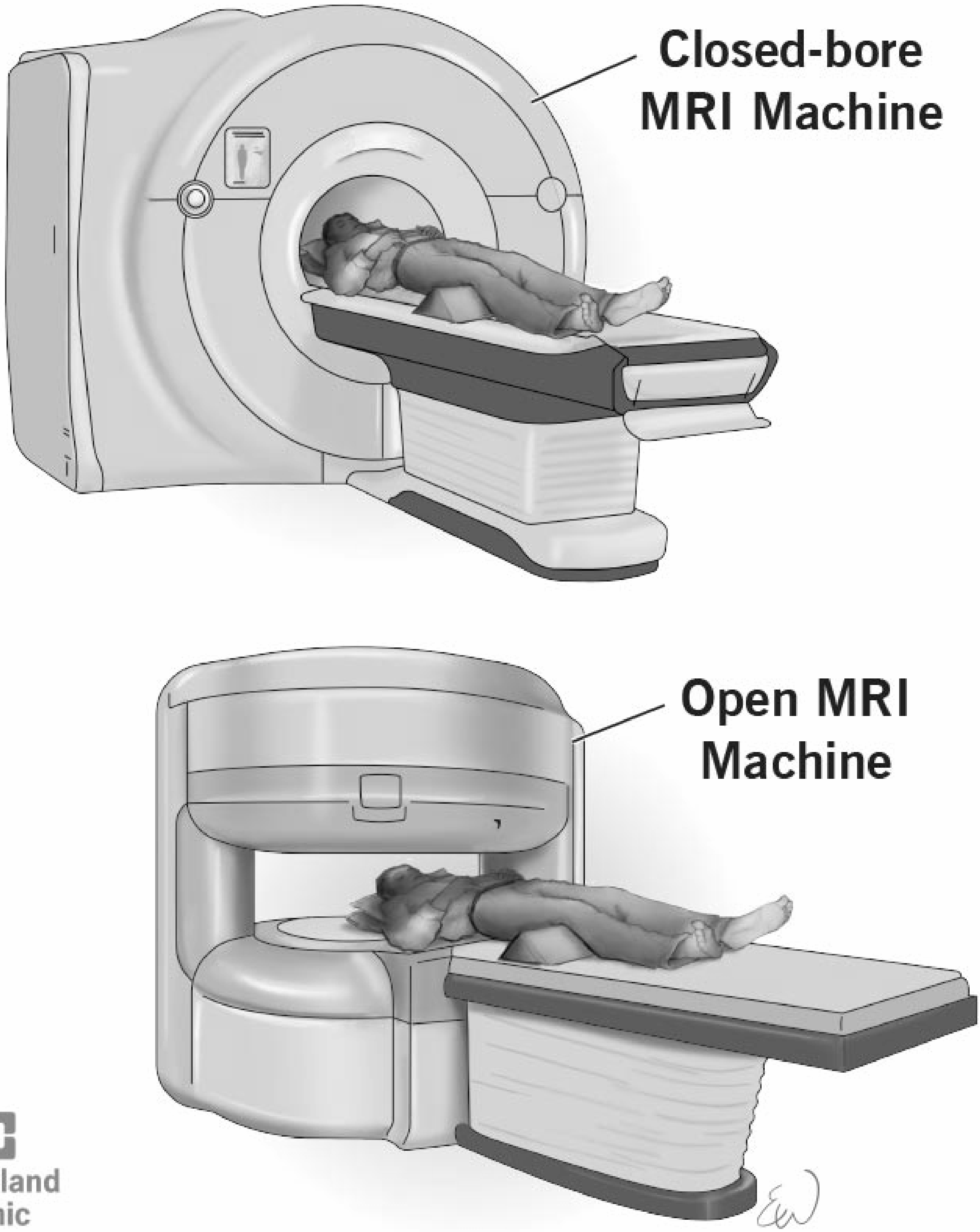
Right Hand Rule

L0
Series L0



$B = \mu_0 n I$
I
I

MRI



LEFT PANEL

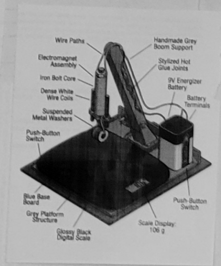
WHAT / HOW

An electromagnetic crane lifts metal objects using a magnetic field generated by electric current. The idea goes back to 1825, when William Sturgeon built the first electromagnet by wrapping wire around an iron bar. My version works the same way.

I wound insulated copper wire around a steel bolt, connected it to a 6V lantern battery through a toggle switch, and mounted the whole thing on a popsicle-stick frame. When the switch is flipped on, current flows through the coils and turns the bolt into a magnet. It grabs washers, nuts, and other steel objects. Flip the switch off, the field dies, and whatever was stuck to it drops. The on/off control is what makes it a crane and not just a magnet.

The iron core matters a lot. Without it, the coil alone produces a field too weak to pick up anything at this voltage. Iron has a relative permeability of about 5000, which means it multiplies the coil's field by roughly that factor. That single material choice is the difference between a working crane and a warm wire.

[Labeled diagram of crane: frame, bolt core, coils, switch, battery, load, scale]



CIRCUITRY

The circuit is a series loop. Battery positive terminal goes to the toggle switch, switch goes to the coiled wire on the bolt, wire returns to the battery's negative terminal. One path, one loop. If anything disconnects, the whole thing shuts off.

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I used a 6V Energizer lantern battery (model 529). At roughly 3 ohms of wire resistance, Ohm's Law gives about 2 amps of current ($I = V/R = 6/3$). That current is what generates the magnetic field. More current would mean a stronger field, but 6V is the limit of the battery.

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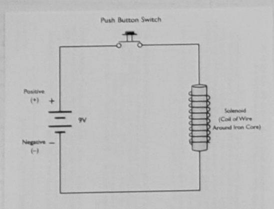
[Circuit diagram: Battery (6V) to Toggle Switch to Coil around bolt, back to Battery]



TERMINOLOGY

Solenoid

A coil of wire that ... current passes through ... electromagnet is

Ferromagnetism

Some metals (iron, steel, nickel, cobalt) can be strongly magnetized. Their atomic magnetic domains line up with an outside field, which makes the net field much stronger. Aluminum and copper are not ferromagnetic, so the crane can't pick them up.

Magnetic Permeability (μ)

How easily a material lets a magnetic field form inside it. Iron's relative permeability is around 5000. Air is 1. That ratio is why the bolt core makes such a big difference.

Magnetic Flux (Φ)

Total magnetic field passing through a cross-section, in Webers (Wb). $\Phi = B \times A$. More flux through the bolt means more pull on nearby metal.

Ampere's Law

Connects the magnetic field around a loop to the current through it. For a solenoid: $B = \mu_0 nI$. Field strength goes up with more turns per metre and more current.

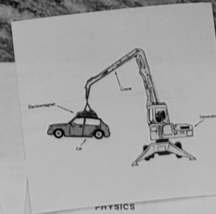
Right-Hand Rule

Curl your right hand's fingers in the direction the current flows through the coil. Your thumb points toward the north pole of the electromagnet.

ELECTROMAGNETIC CRANE

"How can the design of a small-scale electromagnetic crane, including coil count, core material, and circuit control, be optimized to maximize lifting force and allow reliable pickup and release of metal objects?"

Daniel Sultan | SPH4UO Grade 12 Physics



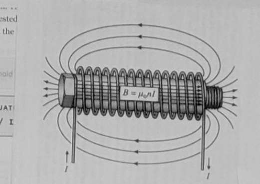
PHYSICS

Magnetic Fields

Current through a straight wire makes a circular magnetic field around it. Coil the wire into a solenoid, and those circles stack into a strong, uniform field running through the center. That is how electromagnets work at a basic level.

But a solenoid by itself is weak at low voltages. Adding an iron core changes everything. The iron has billions of tiny magnetic domains that normally point in random directions. When the solenoid's field hits them, they snap into alignment and add their own magnetic strength. The result: the field inside the core jumps by a factor of roughly 5000. I tested this myself. Without the bolt, the coil couldn't lift a single washer. With the bolt, the same coil pulled 106 grams off a scale.

[Magnetic field lines through solenoid]



SOLENOID FIELD EQUATION

$$B = \mu_0 \cdot \mu_r \cdot (N / L) \cdot I$$

- B = field strength (Tesla)
- $\mu_0 = 4\pi \times 10^{-7}$ T·m/A (free space permeability)
- μ_r = 5000 (iron core)
- N = number of coil turns
- L = solenoid length (m)
- I = current (A)

Two things matter here. B goes up when you add more turns. B goes down when the coil is spread over a longer core. That ratio, N/L (turns per metre), is what controls field strength for a given current.

Electromagnetic Force

The pull between the electromagnet and a piece of steel depends on how strong the field is at the surface and how much contact area there is.

LIFTING FORCE

$$F = (B^2 \times A) / (2\mu_0)$$

Force goes with B squared. That is a big deal. If you double the field, you quadruple the lifting force. Going from 50 to 150 coil turns tripled N, but the force went up by more than 5×. That squared relationship showed up clearly in my data.

Calculations

```
3-wrap coil (150 turns, 4" bolt):
N/L = 150 / 0.102 = 1471 turns/m
Measured lift: 106 g → F = 0.106 × 9.8 = 1.04 N

2-wrap coil (100 turns, 4" bolt):
N/L = 100 / 0.102 = 980 turns/m
Predicted: (980/1471)² × 106 = ~47 g
Measured: 47 g ✓ → F = 0.46 N

1-wrap coil (50 turns, 5" nail):
N/L = 50 / 0.127 = 394 turns/m
Predicted: (394/1471)² × 106 = ~7.5 g
Measured: ~20 g → F = 0.20 N (see deviation analysis)
```

Energy Transfer

Chemical (Battery) → Electrical (Current) → Magnetic (Core Field) → Mechanical (Lift)

Power draw: $P = IV = 6 \times 2 = 12$ W. Most of that becomes heat in the wire (I^2R losses). Only a fraction ends up as useful lifting work. The battery drained noticeably during testing, which reduced current and weakened the field over time.

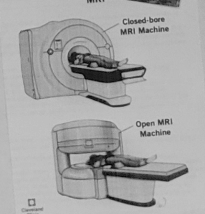
Data Table

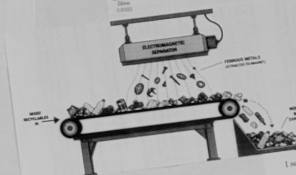
COIL	TURNS	CORE	N/L	PREDICTED	MEASURED	FORCE (N)
3-wrap	150	4" bolt	1471	106 g	106 g ✓	1.04
2-wrap	100	4" bolt	980	~47 g	47 g ✓	0.46
1-wrap	50	5" nail	394	~7.5 g	~20 g *	0.20

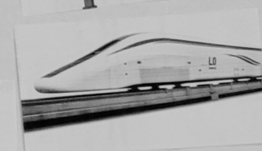
- **Why the 1-wrap nail beat the prediction:** Three things the formula doesn't account for. First, the 5-inch nail has more iron mass, so more material gets magnetized. Second, the nail tip concentrates flux into a small contact point, increasing local field strength. Third, the nail retained some residual magnetism from earlier ...

What Affects Strength

FACTOR	EFFECT	WHAT I SAW
Coil turns (N)	More turns = stronger field	3-wrap lifted 2.25× more than 2-wrap
Current (I)	More current = stronger field	Battery drain weakened performance over time
Core material	Iron multiplies field ~5000×	No lift at all without the bolt
Core length (L)	Longer core = lower N/L	5" nail weaker than 4" bolt at same wraps
Winding quality	Tight coils = cleaner field	Overlapping wraps reduced performance
Contact distance	Force drops fast with gap	Direct contact gave best readings







RIGHT PANEL

APPLICATION

Scrapyard Cranes

Industrial versions of this crane run on 200+ volt DC supplies and use circular electromagnets up to 2 metres wide. They lift entire cars. The operator cuts the current to drop the load. Same physics, different scale.

Recycling

Recycling plants run waste on a conveyor belt under an electromagnet. Steel and iron get pulled up and separated. Aluminum, plastic, and glass pass through. This sorting process recovers up to 95% of ferrous metals from mixed waste, cutting down on mining and landfill.

MRI Machines

Hospital MRI scanners use superconducting electromagnets that produce fields of 1.5 to 3 Tesla. That is thousands of times stronger than my crane. But the idea is the same: current through coils, controlled magnetic field, useful work.

Maglev Trains

Japan's L0 Series maglev hit 603 km/h using electromagnets to lift the train off the track and push it forward. No wheels, no friction. The Shanghai Transrapid runs commercially at 431 km/h. Force scales with B squared there too.

Industrial electromagnetic crane

MRI scanner using superconducting electromagnets

EXPERIMENT

I built three electromagnets to test how coil count ...

I secured the wire ends with hot glue and ran all three off the same battery and switch so the voltage stayed constant across tests.

Method

I piled ferrous objects (washers, nuts, small bolts) onto a digital kitchen scale and tared it to zero. Then I lowered each electromagnet onto the pile, flipped the switch, and read the scale. It showed a negative number, which was the weight being pulled upward. That negative reading is the magnetic lifting force in grams.

Electromagnets A, B, C: different coil wrap counts

Close-up: coil winding density comparison

SIGNIFICANCE

- The 3-wrap coil lifted **106 g (1.04 N)**. The 2-wrap coil lifted **47 g (0.46 N)**. That 2.26× ratio matches the theoretical 2.25× almost exactly, which supports $B = \mu_0\mu_r(N/L)I$ as an accurate model for this setup.
- The 1-wrap coil on the 5-inch nail lifted **~20 g**, beating the 7.5 g prediction. The formula underestimates performance for longer cores because it ignores iron mass, tip flux concentration, and residual magnetism. Real electromagnet design has to account for geometry beyond N/L.
- Without the iron core, the coil couldn't lift anything measurable. The ~5000× permeability boost from iron is what makes the whole crane work.
- Battery drain during testing cut into performance. I noticed weaker lifts on later trials, which lines up with $P = IV$: as voltage drops, current drops, and the field weakens.
- Electromagnetic sorting in recycling plants recovers up to 95% of ferrous metals, reducing mining demand and landfill waste. This project shows the underlying physics behind that process.

RESULTS

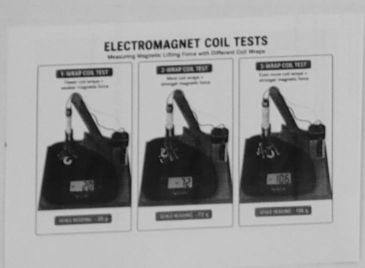
More coils made a stronger field and lifted more weight. 150 turns lifted 106 g, 100 turns lifted 47 g, and 50 turns lifted about 20 g. The trend followed the predicted $F \sim (N/L)^2$ curve closely for the two same-length bolts.

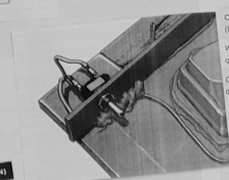
The 5-inch nail produced an interesting deviation. It lifted almost 3× what the formula predicted. This tells me that core geometry, mass, and tip shape matter in ways the basic solenoid equation does not capture. In ...

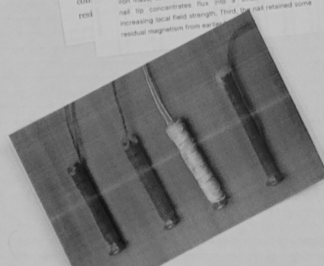
Limit... (I^2R) ...

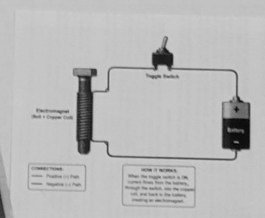
ELECTROMAGNET COIL TESTS

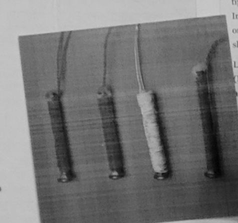
Measuring Magnetic Lifting Force with Different Coil Wraps

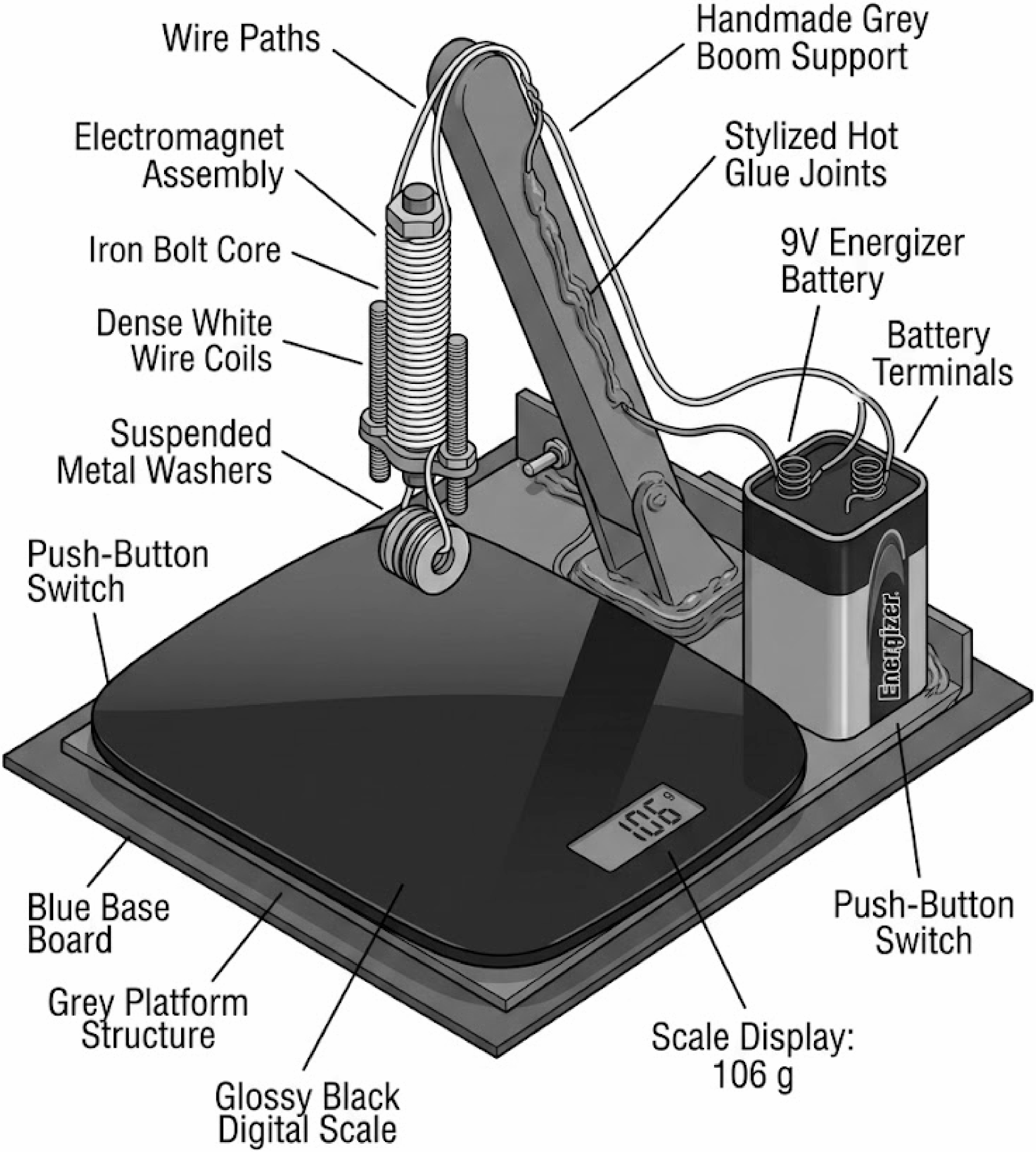




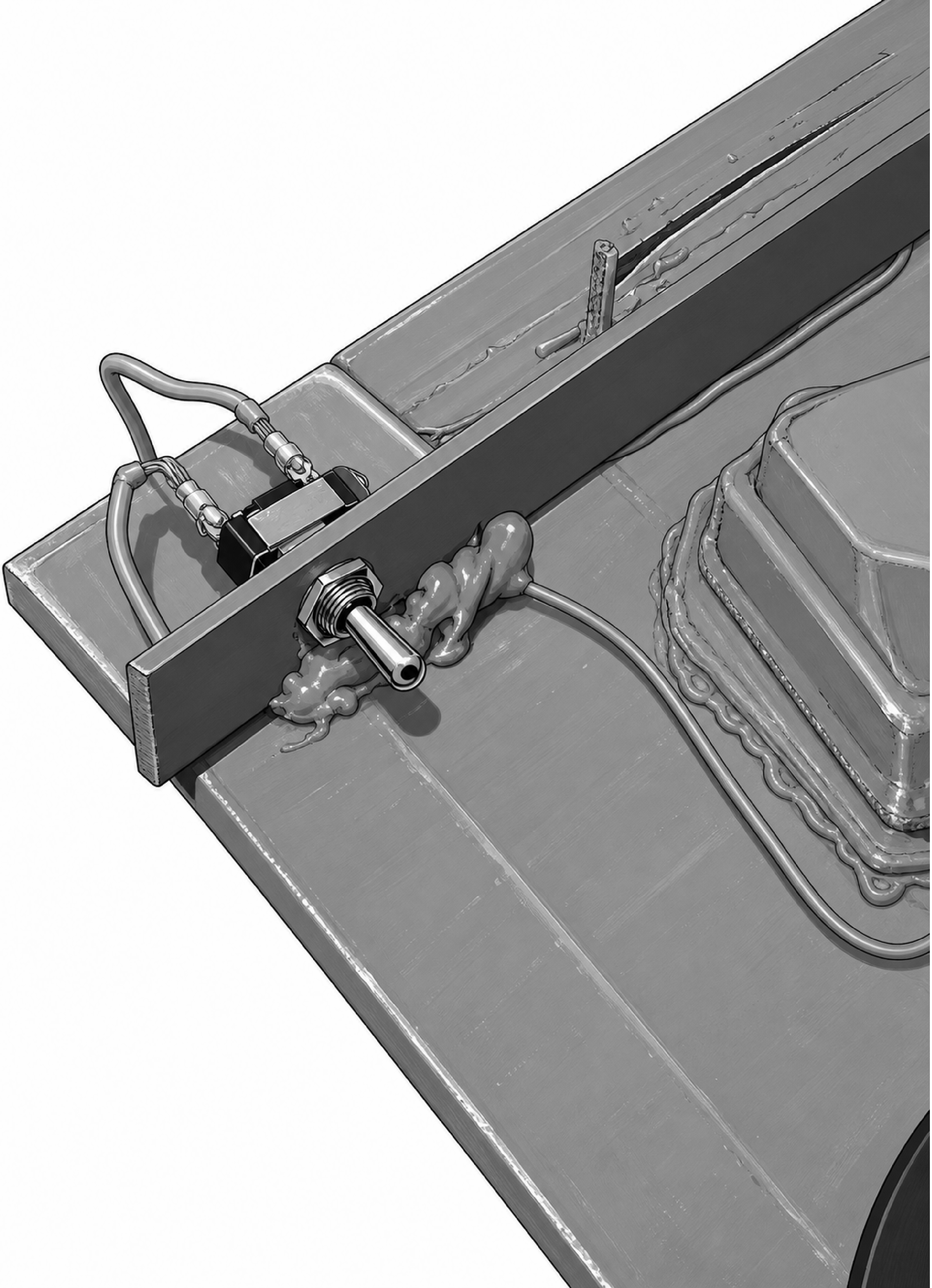


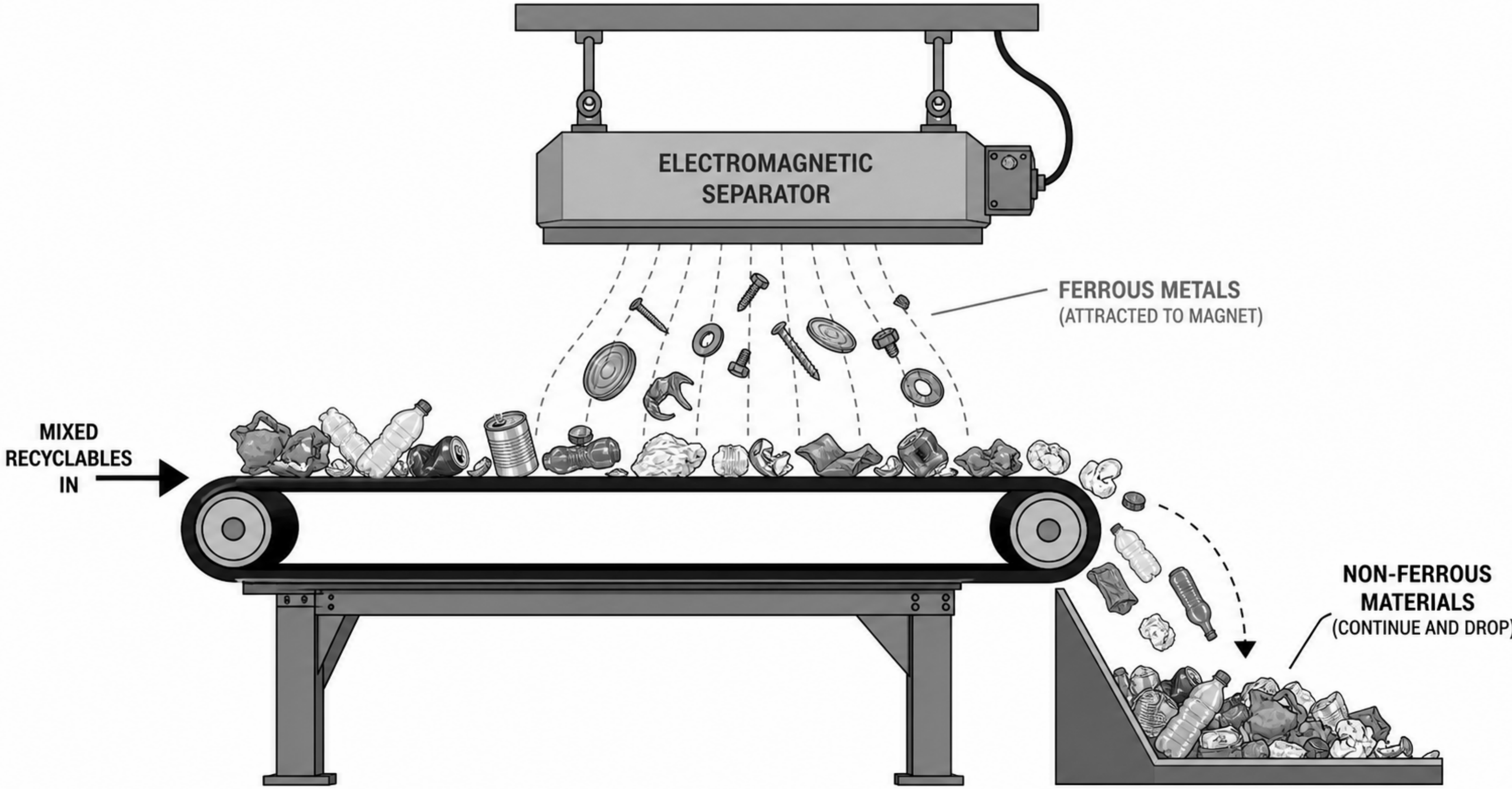


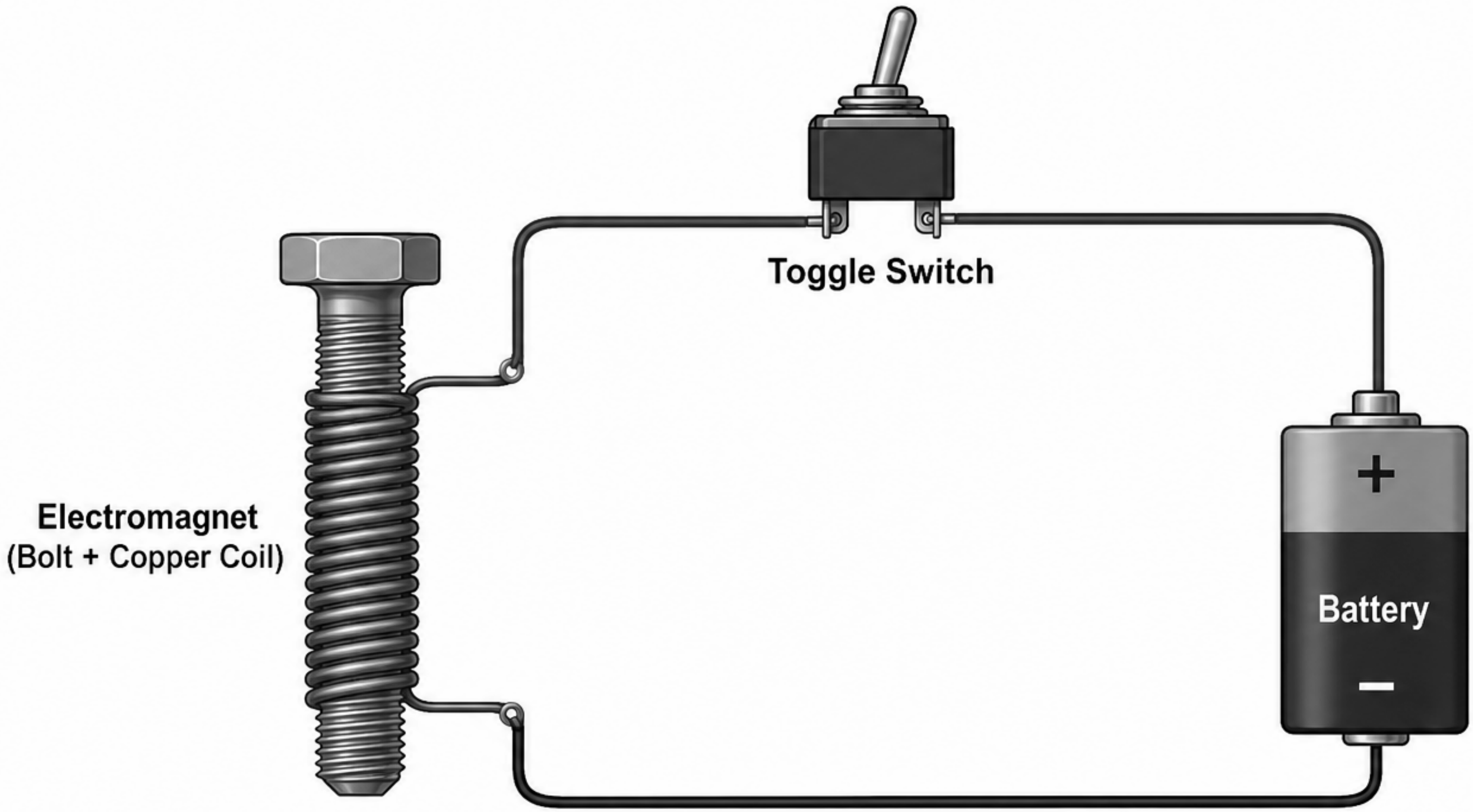




Wire Paths
Handmade Grey Boom Support
Electromagnet Assembly
Stylized Hot Glue Joints
Iron Bolt Core
9V Energizer Battery
Dense White Wire Coils
Battery Terminals
Suspended Metal Washers
Energizer
Push-Button Switch
106 g
Blue Base Board
Push-Button Switch
Grey Platform Structure
Scale Display: 106 g
Glossy Black Digital Scale




ELECTROMAGNETIC SEPARATOR
FERROUS METALS
(ATTRACTED TO MAGNET)
MIXED RECYCLABLES IN
NON-FERROUS MATERIALS
(CONTINUE AND DROP)



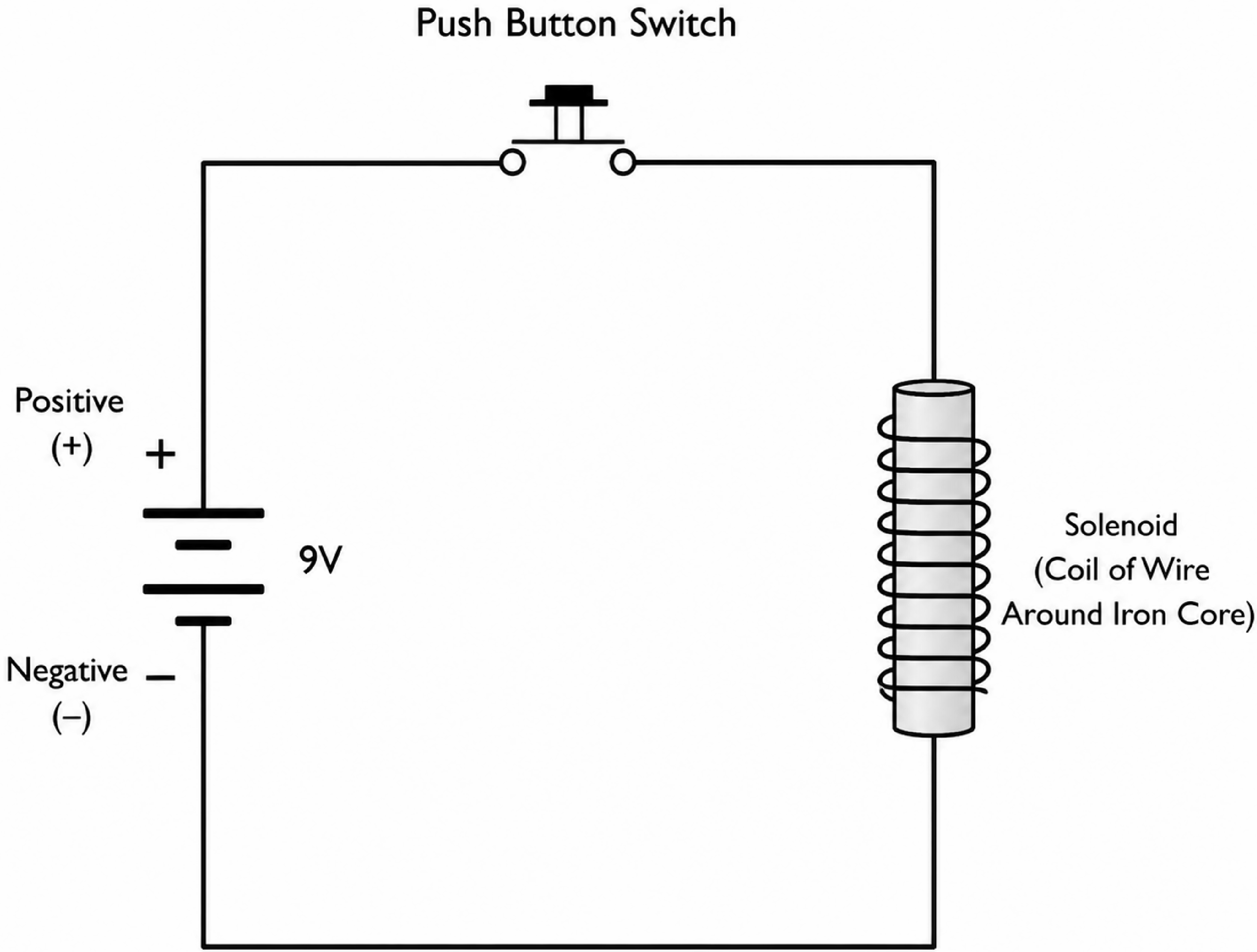
CONNECTIONS:

Positive (+) Path

Negative (–) Path

HOW IT WORKS:

When the toggle switch is ON, current flows from the battery,, through the switch, into the copper coil, and back to the battery, creating an electromagnet.


Push Button Switch
Positive
(+)
+
9V
Negative
–
(–)
Solenoid
(Coil of Wire
Around Iron Core)