Physics 1B
Electricity & Magnetism

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Quiz 2

- Quiz 2 will be on the content of Chapters 20 and 21.
- It will be mostly calculations with no more than 2/10 concept questions.
- It will take place on Monday February 13th during regular lecture in the usual room.
- Please make sure you know your quiz code!

Outline of today

- Finish Chapter 20.
    - Energy of a Capacitor
- Beginning of Chapter 21

Ohm's Law

- No matter how good your conductor is, you are always going to have a minute slowing of current due to the conductor.
- Ohm's Law quantifies the ability of a given material to resist the flow of charge for a given electric potential difference.

$$I = \frac{\Delta V}{R}$$

$$\Delta V = I\,R$$

where R is called the resistance and is measured in Ω (Ohm's).

$[\Omega]$ = [Volt]/[Ampere]

Resistivity

- If I were constructing a wire, for a given battery how could I lower its resistance?
- Use a good conductor.
- Increase its cross-sectional area.
- Shorten its length.

The resistance of an ohmic conductor is given by:

$$R = \rho \frac{L}{A}$$

ρ is called resistivity (depends on the type of material of the conductor).

L is the length of the conductor and A is the cross-sectional area of the conductor.

Resistivity

- <u>Example</u>
- A piece of 20-gauge wire that is one meter long has an electric resistance of 0.050 Ω. Calculate its resistivity. The cross-sectional area of 20-gauge wire is $0.5716 mm^2$.

<u>Answer</u>

No need to define a coordinate system here.

We can turn to the resistivity equation.

Resistivity

<u>Answer</u>

Use:

$$R = \rho \frac{L}{A} \qquad \rho = R\frac{A}{L}$$

We need to convert to the proper units.

$$1\text{m} = 1{,}000\text{mm}$$

$$1\text{m}^2 = (1{,}000\text{mm})^2 = 1.0 \times 10^6\text{mm}^2$$

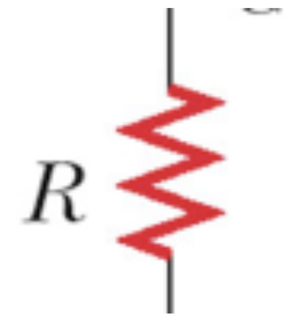
$$\rho = (0.05\Omega)\frac{(0.5176\text{mm}^2)}{1\text{m}}\frac{1\text{m}^2}{1.0\times 10^6\text{mm}^2}$$

$$\rho = 2.6 \times 10^{-8}\,\Omega\cdot\text{m}$$

Turns out to be Aluminum

Resistors

- Resistors are put in circuits to control the current available.
- When we draw resistors in circuits we will draw it as choppy, connected section.



If a wire has negligible resistance, then we will represent it with a straight line.

We will consider all wires in a circuit diagram to have negligible resistance unless otherwise stated.

All resistors will have a potential difference across them (if current passes through them).

Power

- Recall from mechanics that power was a measure of the work done in a given amount of time:

$$\text{Avg. Power} = \mathcal{P}_{avg} = \frac{Work}{time} = \frac{W}{\Delta t}$$

The SI unit of power is still the Watt (Joule/sec).

Work is also how much your potential energy has changed (assuming KE is constant).

$$\mathcal{P} = \frac{\Delta PE}{\Delta t}$$

Power

In a circuit, you will get power from a small amount of charge (Δ q) moving across a potential difference (Δ V).

$$P = \frac{\Delta(qV)}{\Delta t} = \frac{\Delta(q)}{\Delta t}\Delta V$$

$$P = I(\Delta V)$$

This is the power that is transferred by electrical energy.

Sometimes we write as:

$$P = IV$$

Power

If you would like to find the power dissipated (lost) by resistance in a device use Ohms' Law ($\Delta V = IR$):

$$P_{dis} = I(\Delta V) = I(IR) = I^2 R$$

$$P_{dis} = I(\Delta V) = \frac{\Delta V}{R}(\Delta V) = \frac{(\Delta V)^2}{R}$$

These two equations are used to calculate power dissipation (the energy lost due to resistive effects).

This power will never be recovered (it becomes heat, light, or some other form of energy).

Power

When you transfer power over a time period to an element you are essentially transferring energy.

The unit of energy used by the electric company is the kiloWatt-hour.

Where 1kWh = 3.60×10^6 J.

This energy could go into raising a mass:

$$\Delta PE = mg\Delta y$$

or heating water... or anything

$$Q = \Delta E = mc\Delta T$$

Power

- Why do electric companies make power lines with very high voltages to deliver electricity to your house?
- Let's make some estimations:
- R = 10Ω, V = 100,000V to deliver 100kW of power.
- First, don't make a common mistake:

$$P_{dis} = \frac{V^2}{R} = \frac{(100{,}000\text{V})^2}{10\Omega} = 1.0\times10^9\text{W}$$ <-no!

This equation can only be used with a potential difference (Δ V) across a resistor.

Power

- Instead we will find the current by the power transfer equation.

$$P = IV$$

$$I = \frac{P}{V} = \frac{100\text{kW}}{100{,}000\text{V}} = 1\text{A}$$

Now we can input this current in the proper power dissipation equations.

$$P_{dis} = I^2 R = (1A)^2 10\Omega = 10\text{W}$$

This only represents a 0.01% loss of power transferred to resistive effects (not bad!).

Power

- What if power companies used lower potential for their transmission lines (say 2,000V)?

$$P = IV$$

$$I = \frac{P}{V} = \frac{100\text{kW}}{2{,}000\text{V}} = 50\,\text{A}$$

Now we can input this current in the proper power dissipation equations.

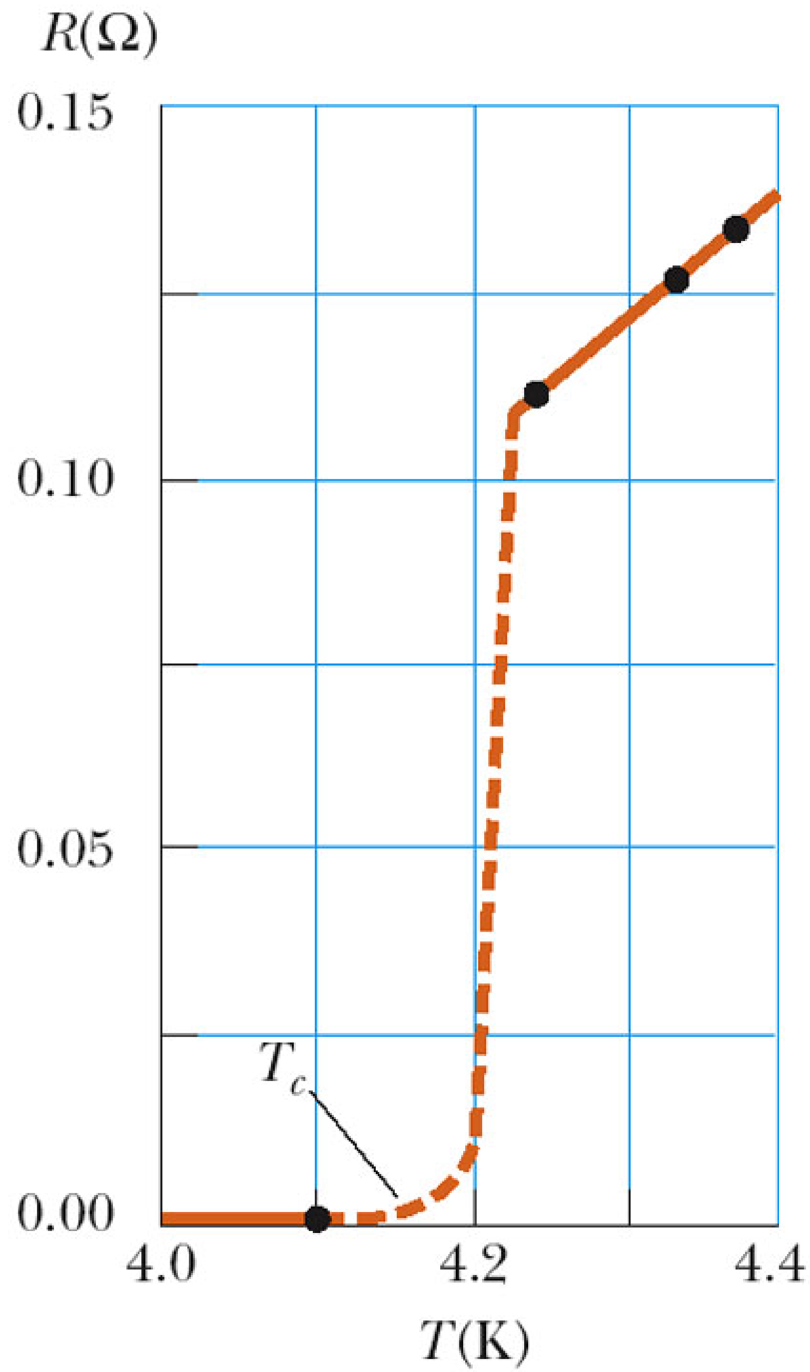
$$P_{dis} = I^2 R = (50\,A)^2 10\Omega = 25{,}000\text{W}$$

25% of power is lost to heat. That isn't good business.

Superconductors

- Supercondutors can help solve these problems.
- Superconductors are materials whose resistance falls to virtually zero below a certain critical temperature, T_C.

Once a current is set up in a superconductor, it persists without any applied potential difference.



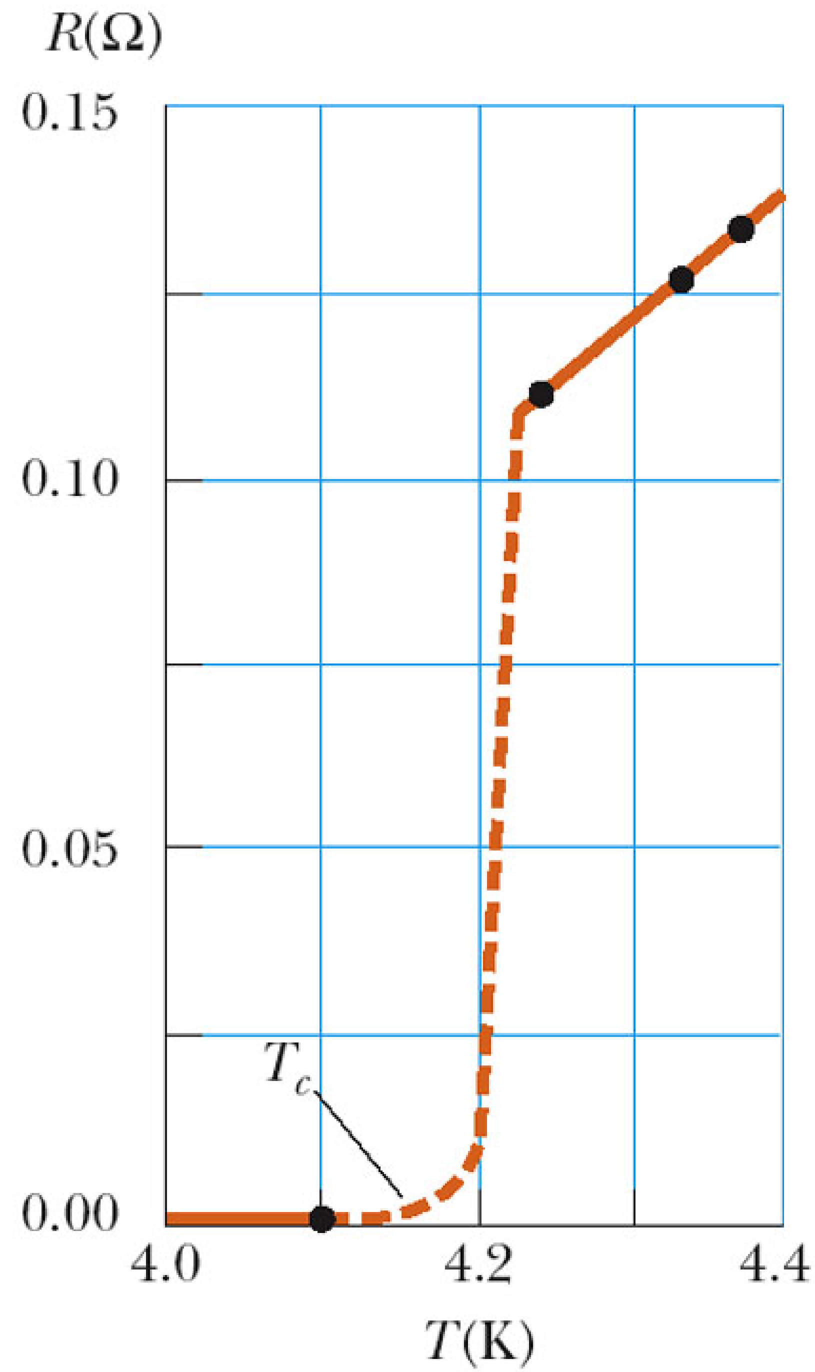
Superconductors

Above T_c, the superconductor acts as a normal metal.

Unfortunately superconductors currently only exist at low temperatures (highest ~150K)

[–123°C].

But we are getting closer to room temperature superconductivity. In the mid-80's the highest was near 30K [–243°C].

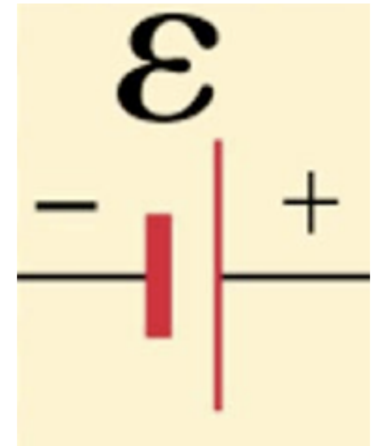


Batteries

- As we have stated before, the cause of current flow is an electric potential difference, ΔV.
- Batteries supply energy to keep "pumping" charge carriers.
- We term this "pumping" as emf, ε. (It stands for electromotive force, problem not a force).
- A device which provides emf will perform work on charges to keep them moving.
- So, basically emf is a voltage difference provided by a source.

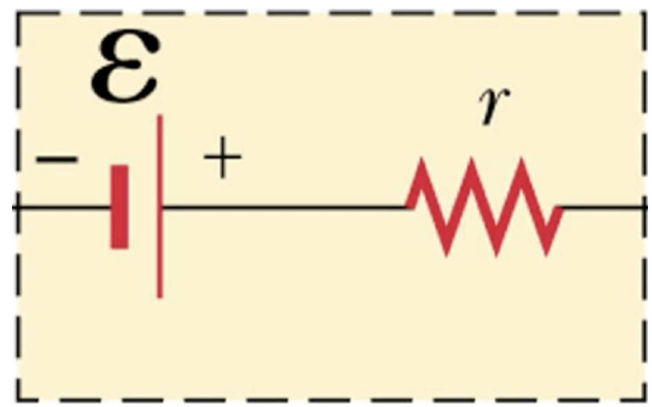
Batteries

- There are three basic types of emf:
- 1) Ideal Battery: a battery that lacks internal resistance.



2) Real Battery: a battery that contains internal resistance, r, that hampers current flow.

Note the internal resistance is in series with the battery.



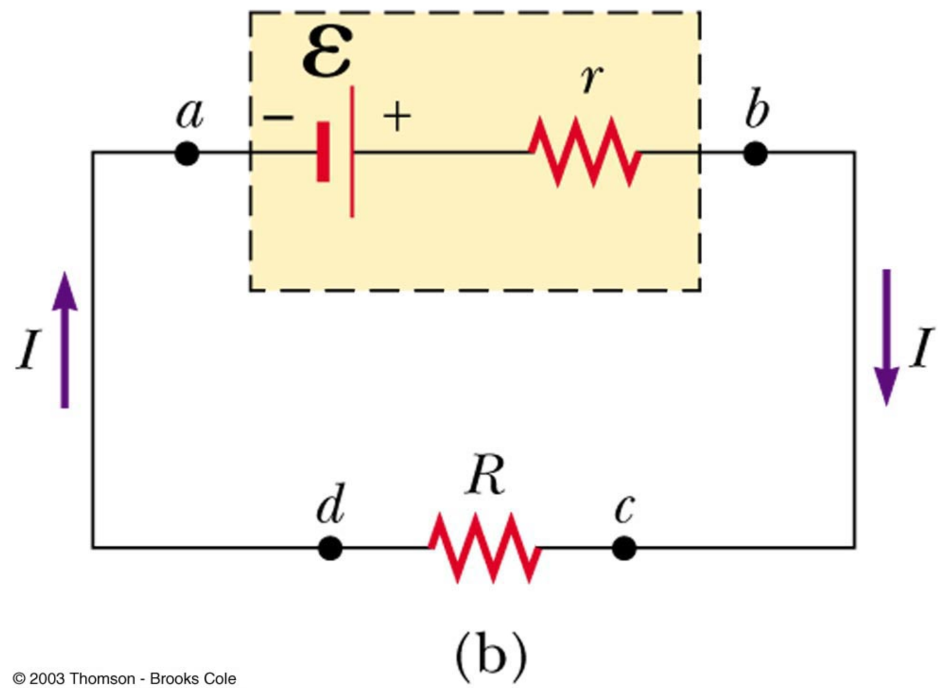
3) Generator: a device that uses mechanical energy to create electrical energy.

Batteries

- Internal resistance, r, will effectively lower the emf of the battery and, thus, must be taken into account.
- For now we will assume that all batteries are ideal unless specifically told otherwise.
- If you do encounter internal resistance know that:

$$\Delta V_{ba} = V_b - V_a$$

- $\Delta V_{ba} = \varepsilon - Ir$
- For this circuit:
- $\varepsilon = IR + Ir$



A Good Battery

- A good battery is one for which very little of the energy in the battery is wasted by dissipating energy in the internal resistor
- $\varepsilon = IR + Ir$
- $P = I^2 (R + r)$
- You thus want $r << R$
- Whether or not a given battery is good enough for the circuit you are building thus depends on the R of the circuit, and the amount of power you are willing to waste.

For Next Time (FNT)

- Continue homework for Chapter 21
- Continue reading Chapter 21