DC Circuits I

Physics 2415 Lecture 12

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Today’s Topics

- Mention of AC
- Semiconductors and superconductors
- Battery emf, internal resistance
- Series and parallel resistances
- Kirchhoff’s rules

AC and DC

- Batteries provide direct current, DC: it always flows in the same direction.
- Almost all electric generators produce a voltage of sine wave form:

$$V = V_0 \sin 2\pi ft = V_0 \sin \omega t$$

- This drives an alternating current, AC,

$$I = \frac{V_0 \sin \omega t}{R} = I_0 \sin \omega t$$

and power

$$P = VI = I^2 R = I_0^2 R \sin^2 \omega t = \left(V_0^2 / R \right) \sin^2 \omega t$$

AC Average Power and rms Values

- The AC power $P = \left(V_0^2 / R\right)\sin^2 \omega t$ varies rapidly ($\omega = 2\pi f$, f = 60 Hz here), what is significant for most uses is the average power.
- The average value of $\sin^2 \omega t$ is ½.
- Define V_{rms} by $V_{\text{rms}} = \sqrt{\overline{V^2}} = V_0 / \sqrt{2}$
- Then the average power $\bar{P} = V_{\text{rms}}^2 / R$

average value of $\sin^2 \omega t$ must equal average value of $\cos^2 \omega t$. and remember $\sin^2 \omega t + \cos^2 \omega t = 1$

The standard 120V AC power is V_{rms} = 120V.

So the *maximum* voltage V_0 on a 120V line is 120x√2 = 170V!

Sometimes DC *is* used for a Single Long Line

- This 3 gigawatt DC line (enough for 2 to 3 million households) transmits hydropower from the Columbia river to Los Angeles.
- At these distances, it gets tricky synchronizing the phase of AC power.

Semiconductors

- In the Bohr model of the hydrogen atom, an electron circles around a proton.
- An n-type semiconductor is a dielectric insulator which has been doped—atoms having one more electron than the insulator atoms are scattered into it.
- The extra electron circles the dopant atom, but is loosely bound because the dielectric shields the electric field—it looks like a big Bohr atom. As the temperature is raised, these electrons break away from their atoms, and become available to conduct electricity.
- Bottom Line: Conductivity *increases* with temperature.

Superconductors

- A superconductor has exactly zero resistivity.
- In 1911, mercury was discovered to superconduct ($R = 0$) when cooled below 4K.
- Superconducting magnets are widely used, in MRI machines, etc.
- There are now materials superconducting above the boiling point of liquid nitrogen, making long distance transmission lines feasible.
- Superconductivity is a quantum phenomenon.

Battery emf $\mathcal{E}$

- At the terminals inside a battery, a precise voltage is generated by the particular chemical energy exchanges taking place (electron capture or donation by molecules at the terminals).
- This voltage is called the electromotive force (even though it's a potential energy, it *does* drive the current around a circuit), and is denoted by emf or $\mathcal{E}$.

The emf $\mathscr{E}$ and *Internal* Resistance

- This chemically generated voltage $\mathscr{E}$ also has to push the current through the battery itself.

- The battery has an internal resistance, usually denoted by r, so for a current I in the circuit, the battery supplies to the outside world a terminal voltage

  - $V = \mathscr{E} - Ir$

- (This is usually a small effect and can be neglected.)

Resistances in Series

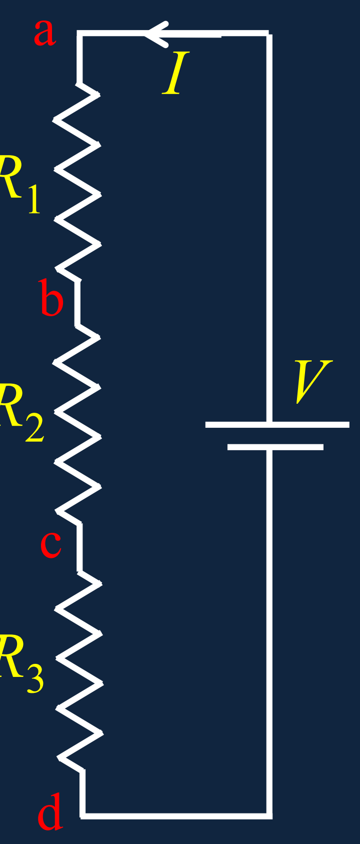
- A battery voltage V pumps a steady current I through 3 resistances <u>in series</u>, as shown.
- Think of the battery as a pump, raising the potential of charge, which then drops in the R's, like a series of waterfalls a → b → c → d.
- From Ohm's Law, the potential drops are:

$$V_{ab} = IR_1, \quad V_{bc} = IR_2, \quad V_{cd} = IR_3.$$

- So the total drop $V = V_{ad} = V_{ab} + V_{bc} + V_{cd} =$

$IR_1 + IR_2 + IR_3 = IR,$

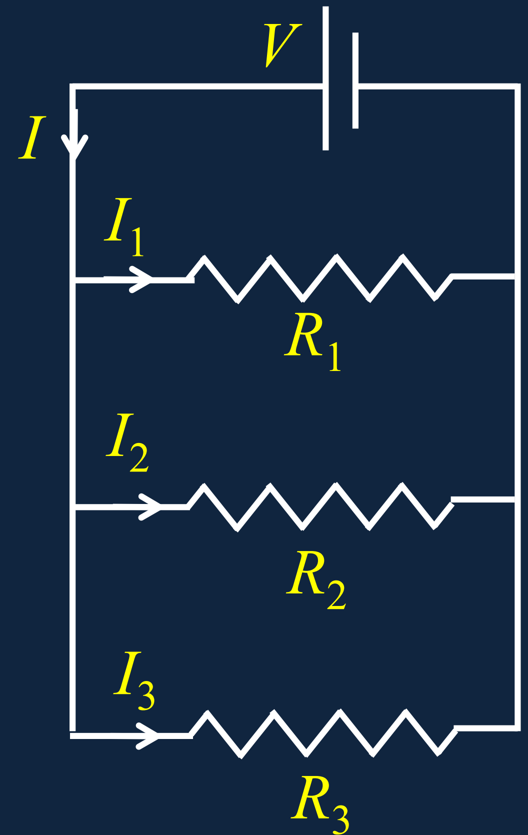
where the total resistance $R = R_1 + R_2 + R_3$



Resistances in Parallel

- (Convention: lines without zigzag represent wires of negligible resistance.)
- This means all three of the resistances shown have the same voltage V between their ends.
- So $V = I_1R_1 = I_2R_2 = I_3R_3$
- The total resistance is defined by $V = IR$.
- Now $I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} = \frac{V}{R}$,

giving $$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



Clicker Question

- Which has the greater resistance,

A. A 120V 60W bulb?

B. A 120V 30W bulb?

Clicker Question

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B. A 120V 30W bulb? ←

Remember power $P = VI = V^2/R$. V is the same for both, so lower R means higher power.

Clicker Question

- If a 60W bulb and a 100W bulb are connected in series to a 120V supply, which will be brighter?

A. The 60W bulb

B. The 100W bulb

C. They'll be equally bright

Clicker Answer

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A. The 60W bulb ←

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D. The 60W bulb has greater R, so more voltage drop—and power = VI, they have the same I.

Remember…

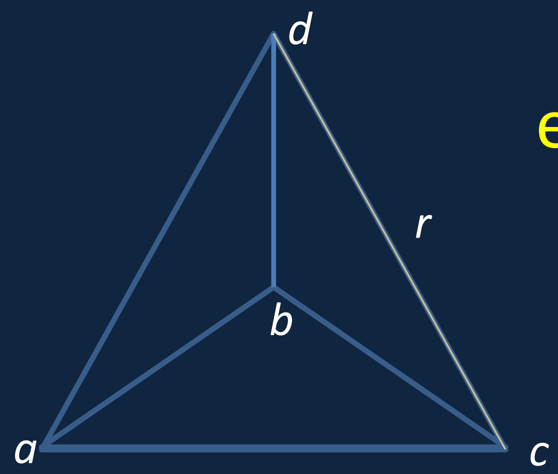
- Resistances in series all carry the same current
- Resistances in parallel all have the same voltage drop
- Put this together with Ohm’s law for each resistance.

General Circuits: Kirchhoff's Rules

- **Junction Rule:** when several wires meet at a point, the total current flowing into the point must equal the total current flowing out. Charge cannot disappear, or pile up at a point.
- **Loop Rule:** the total potential (voltage) change on following wires around a loop to your starting point must be zero.

- (*The loop rule is equivalent to saying that if you follow some random path on a hillside, and get back eventually to your starting point, your net change in height above sea level is zero*.)

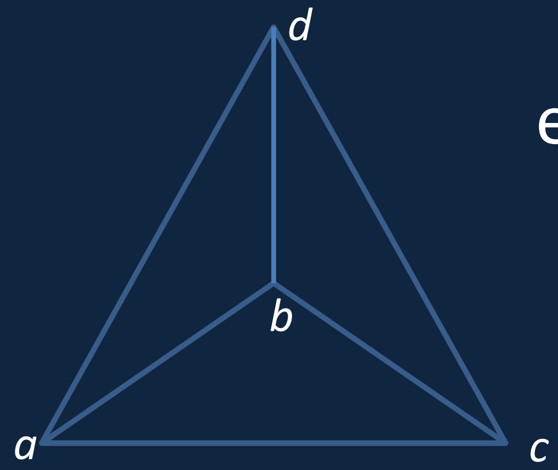
Clicker Question



All lines have resistance 1 except *dc*, which has resistance *r*. If a voltage *v* is applied from *a* to *b*, which way does current flow in *dc*?

A. From *d* to *c*
B. From *c* to *d*
C. There is no current

Clicker Answer



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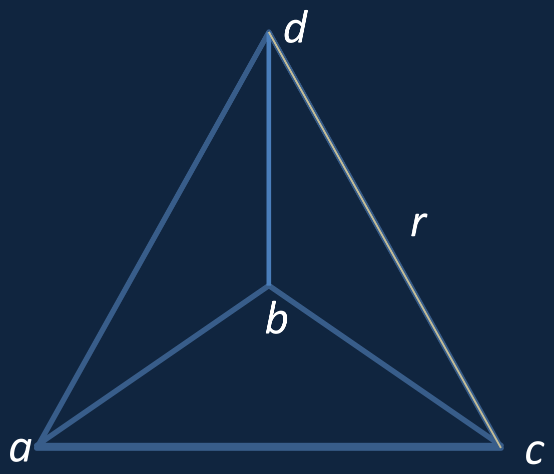
A. From *d* to *c*

B. From *c* to *d*

C. There is no current

There is no current because the situation is completely symmetrical: symmetry can sometimes simplify circuit analysis.

Problem



All lines have resistance 1 except *dc*, which has resistance *r*.

If now a voltage 10V is applied from *a* to *c*, what is the total current flow?