DC Circuits I

Physics 2415 Lecture 12

Michael Fowler, UVa

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. 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 $\mathscr{E}$

- 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 trerminals).
- This voltage is called the electromotive force (evne though it's a potential energy, it *does* drive the current around a circuit), and denoted by emf or $\mathscr{E}$.

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

- This chemically generated voltage $\mathcal{E}$ 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
  - $V = \mathcal{E} - Ir$
- (This is usually a small effect and can be neglected.)

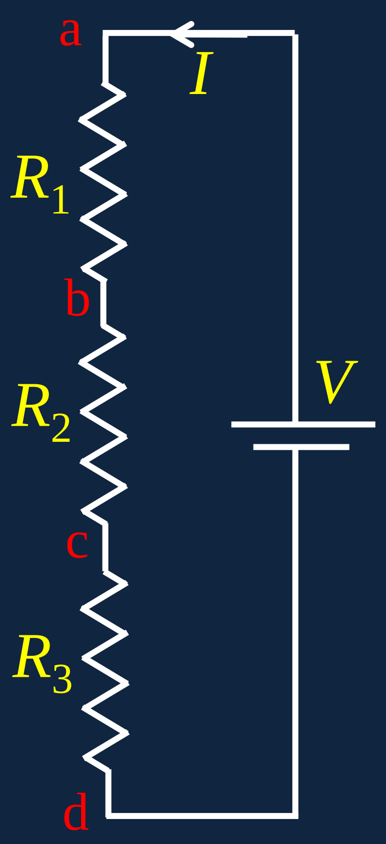
Resistances in Series

- 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 $R = R_1 + R_2 + R_3$

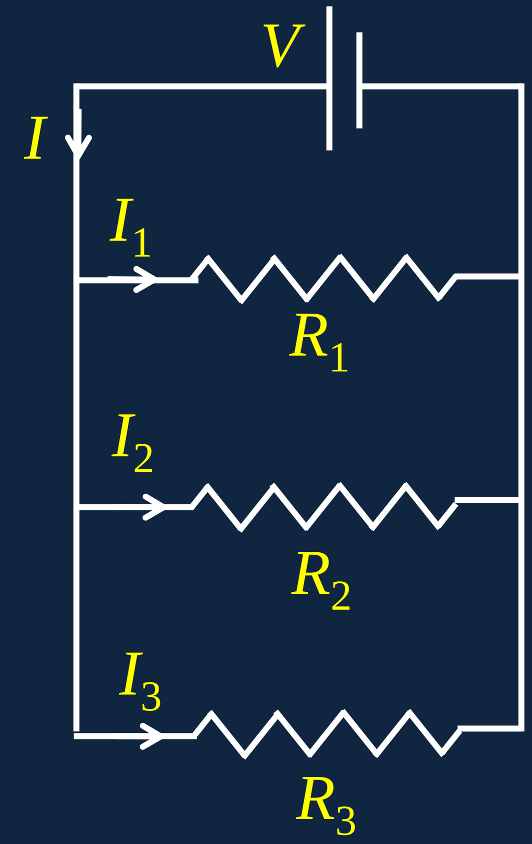


Resistances in Parallel

- (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 $I = I_1 + I_2 + I_3 = \dfrac{V}{R_1} + \dfrac{V}{R_2} + \dfrac{V}{R_3} = \dfrac{V}{R}$,

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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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 ←
B. The 100W bulb
C. They'll be equally bright
D. The 60W bulb has greater R, so more voltage drop—and power = VI, they have the same I.

Remember…

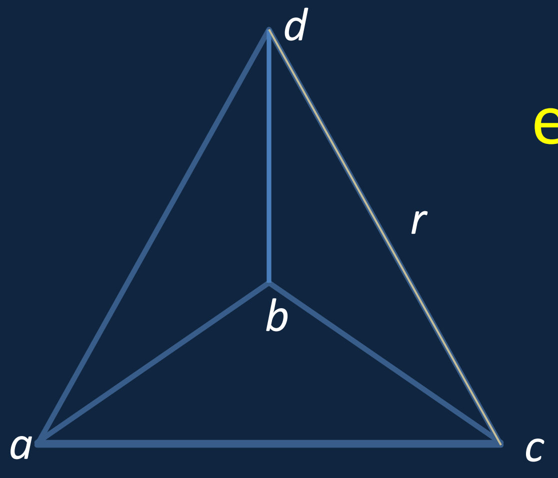
- Resistances in series all carry the same current
- Resistances in parallel all have the same voltage drop
- Put this together with Ohm's law for each resistance.

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*.)

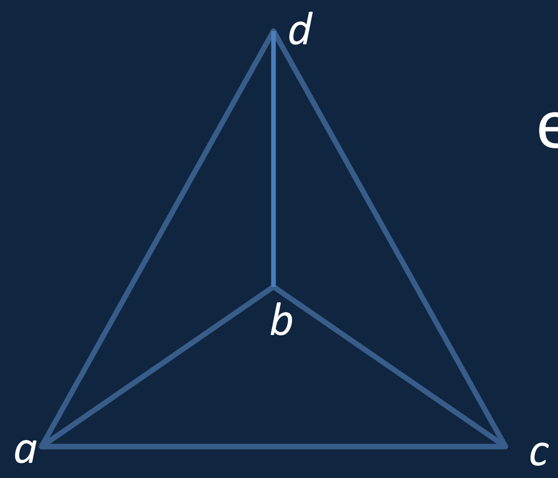
Clicker Question



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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B. From *c* to *d*
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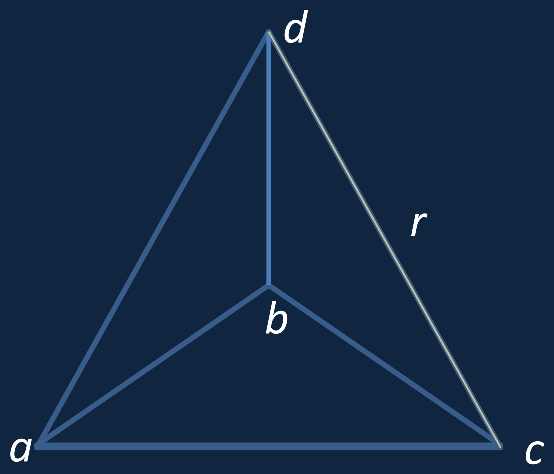
There is no current because the situation is completely symmetrical: symmetry can sometimes simplify circuit analysis.

Problem



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

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