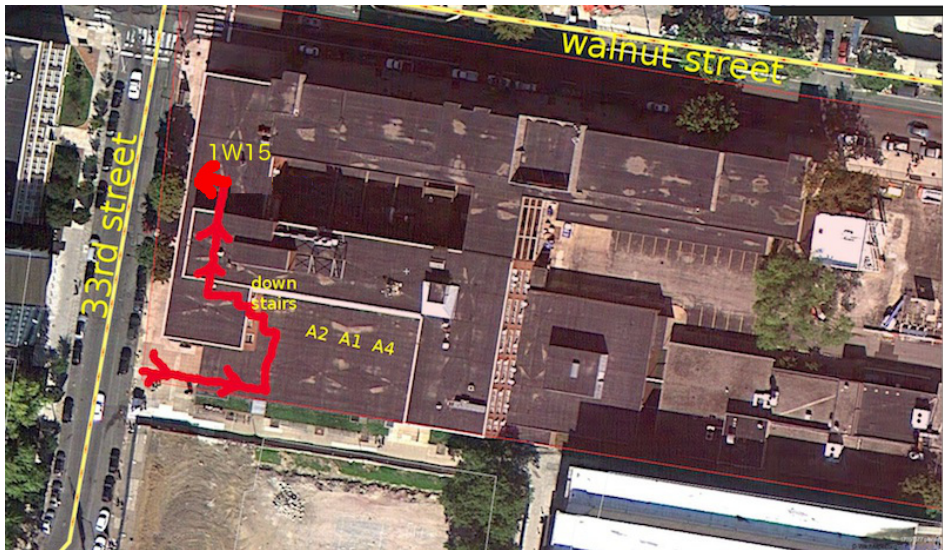






Physics 9 — Monday, December 10, 2018

- ▶ Turn in practice exam now, or in my office (DRL 1W15).
http://www.hep.upenn.edu/~ashmansk/drl1_1w15.jpg
- ▶ Final exam Mon 12/17 12pm–2pm DRL A6. You can bring one sheet of your own hand-written notes, which (if you bring one) you will turn in with your exam.
- ▶ FYI: positron.hep.upenn.edu/wja/p009/2016/files/exam.pdf
positron.hep.upenn.edu/wja/p009/2016/files/exam_solns.pdf
- ▶ Note grading scheme at
<http://positron.hep.upenn.edu/p9/#grading>
Unless anyone objects, I will reduce class participation weight from 5% to 2%, increase homework weight from 50% to 51%, and increase reading weight from 10% to 12%.
- ▶ Exam review session Saturday early afternoon??



- ▶ Since 14 of you did the (optional/XC) Arduino reading, does anyone want to work in small groups with Arduinos and breadboards for a couple of hours during Reading Days? (Or potentially also next Tue/Wed after our exam.)
- ▶ <https://doodle.com/poll/hwf78raekknb2ey>

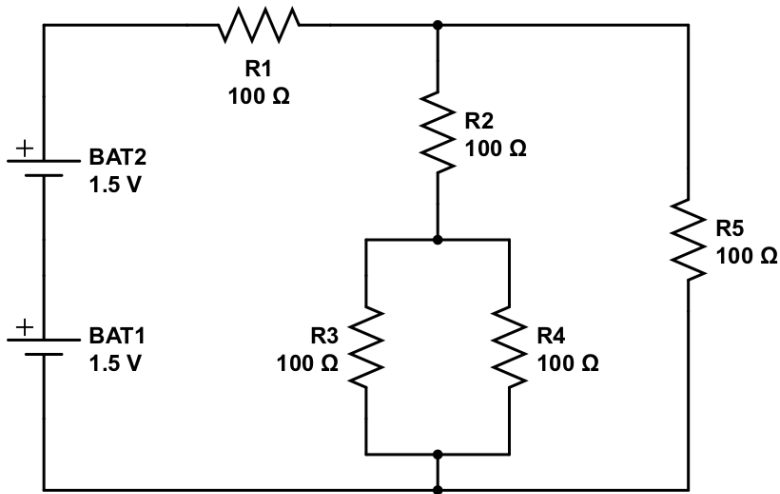
	Table Calendar					
	Dec 11 TUE 11:00 AM 1:00 PM	Dec 11 TUE 1:00 PM 3:00 PM	Dec 11 TUE 3:00 PM 5:00 PM	Dec 12 WED 11:00 AM 1:00 PM	Dec 12 WED 1:00 PM 3:00 PM	Dec 12 WED 3:00 PM 5:00 PM
3 participants	✓2	✓0	✓1	✓2	✓1	✓0
 Bill Ashmanskas	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
 Julian Merchant			✓	✓	✓	
 Djavaneh	✓			✓		
 Choyce Bostian III	✓					

- ▶ Other XC options: read/summarize Muller PTFP chapters:
 - ▶ 04 – nuclei and radioactivity
 - ▶ 05 – chain reactions, nuclear reactors, and atomic bombs
 - ▶ 11 – quantum physics
 - ▶ 12 – relativity
 - ▶ 13 – the universe
 - ▶ `muller_effp_ch3.pdf` is a slightly more up-to-date (2012) chapter by Muller on Climate Change
- ▶ Or you can read/summarize one or more chapters from an Architectural Acoustics book by Egan (`egan_ch1.pdf` etc.)
- ▶ Or read/summarize 3 Eric Mazur chapters giving a more mathematical look at entropy & thermodynamics.
- ▶ Giancoli's chapter on astronomy (or others if you like)
- ▶ Or read+do tutorials on Mathematica for math calculations
- ▶ Or code in Processing (java or python): see my Nov 21 slides
- ▶ Or try out Pachyderm Acoustics or Odeon
- ▶ Or read/skim and summarize key points of §I (“numbers”) and §II (“making a difference”) of *Sustainable Energy — without the hot air*, by David MacKay. It’s “the Freakonomics of conservation, climate, and energy.” (Early 2009.) You can read it online for free at <http://www.withouthotair.com>

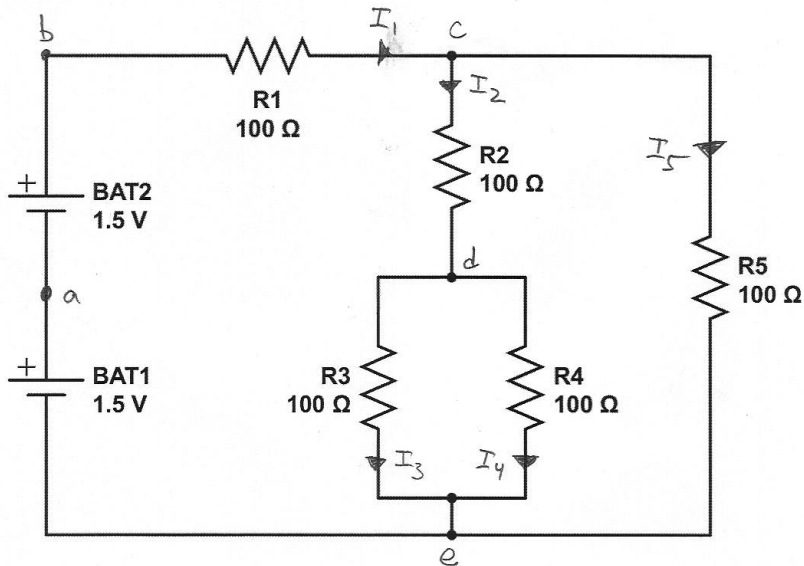
Other demos:

- ▶ speaker
- ▶ household wiring
- ▶ GFCI
- ▶ animation of **alternating current** (AC)
<https://www.youtube.com/watch?v=0wgoPM13kIs>

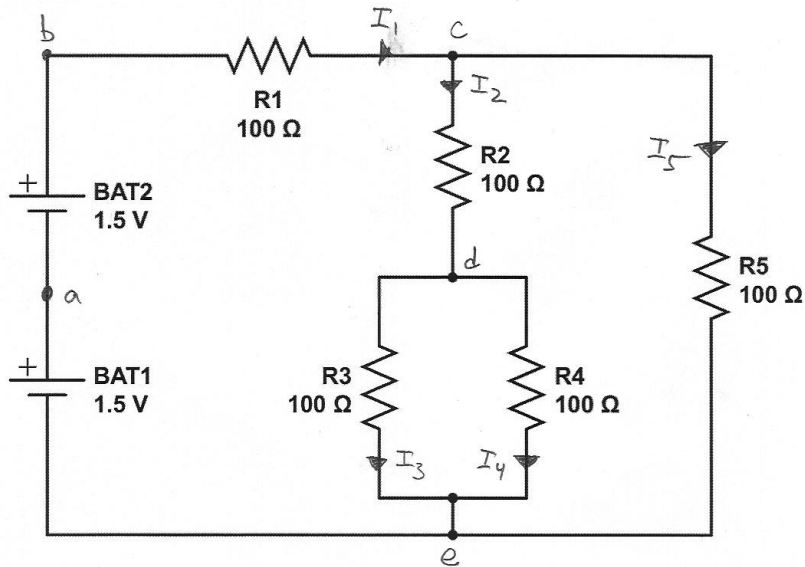
From here, skip ahead to alternating current.



This circuit is more complicated. How many branches? Let's choose a reference direction for each branch, choose a name for the current in each branch, and choose a name for all points between which we might want to measure voltage. (Next page.)



What does junction rule let us write at point *c*? Point *d*? Does the junction rule at point *e* tell us anything new?



I count 4 loops. Let's see what the loop rule tells us. Again, one equation will be redundant. We'll just write down the equations, without wasting time to solve them for $I_1 \dots I_5$.

loop rule:

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_5 R_5 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - I_3 R_3 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - I_4 R_4 = 0$$

junction rule:

$$I_1 = I_2 + I_5 \Rightarrow \boxed{I_5} = I_1 - I_2$$

$$I_2 = I_3 + I_4 \Rightarrow \boxed{I_4} = I_2 - I_3$$

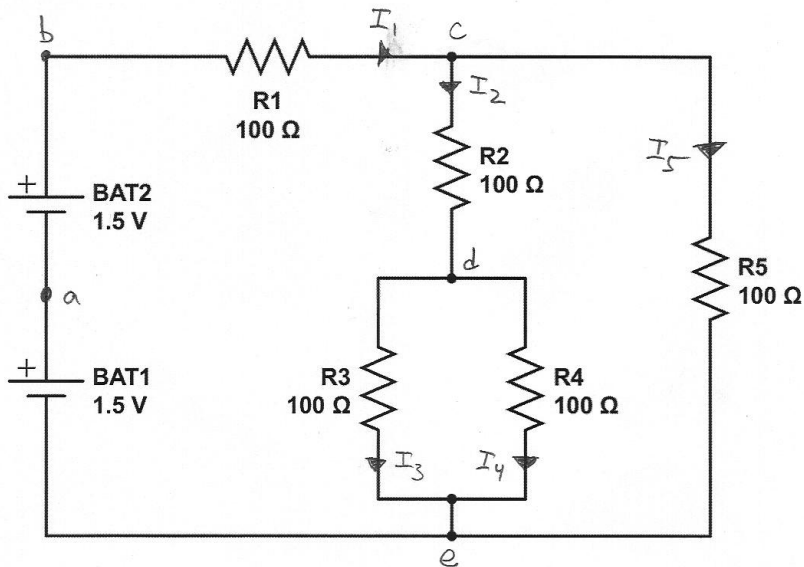
Plug these in to eliminate I_4, I_5 :

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - (I_1 - I_2) R_5 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - I_3 R_3 = 0$$

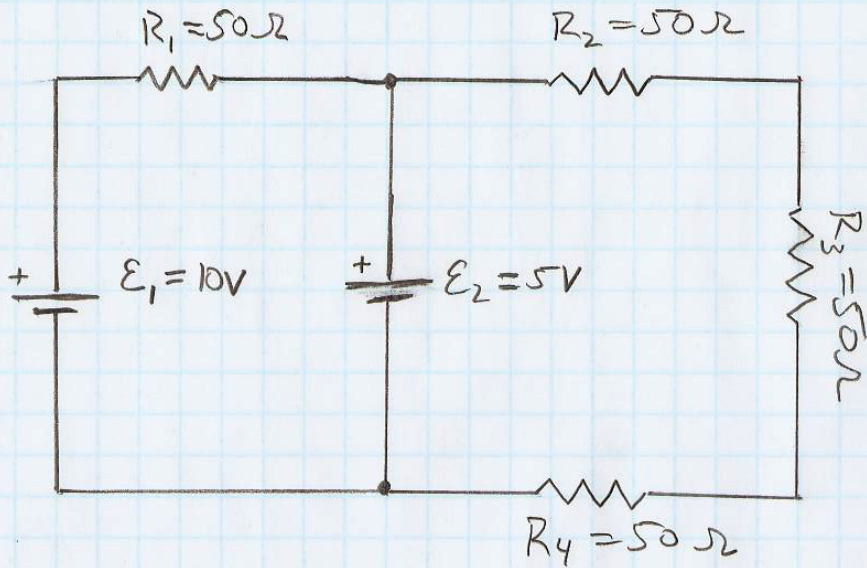
$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - (I_2 - I_3) R_4 = 0$$

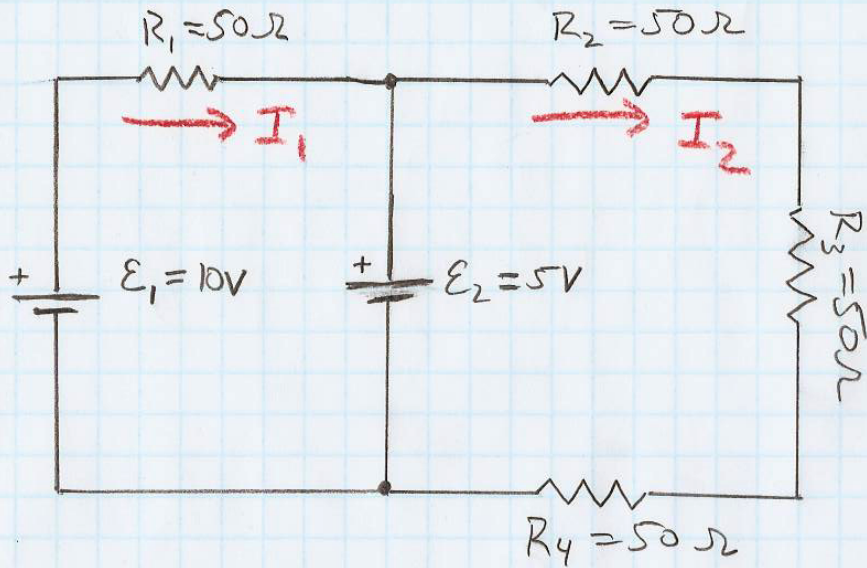
Notice that $I_3 R_3 - I_4 R_4 = 0$ is same as
we would get by subtracting the last 2 eqns.

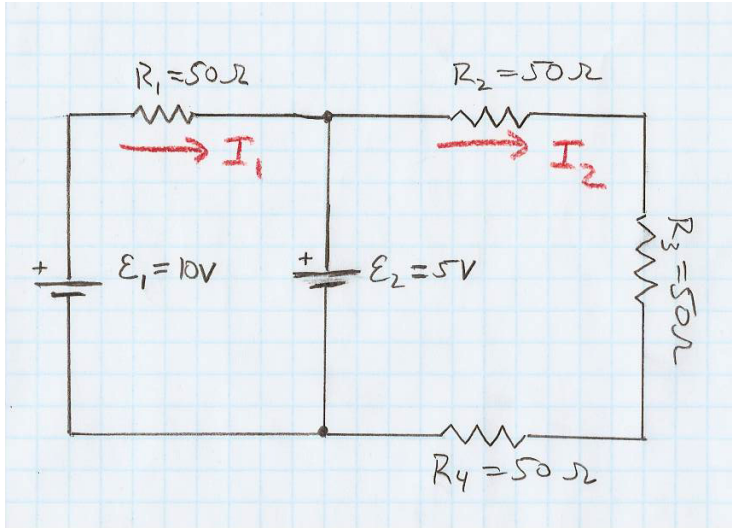


$$I_1 = 0.01875 \text{ A}, I_2 = 0.0075 \text{ A}, I_3 = I_4 = 0.00375 \text{ A}, I_5 = 0.01125 \text{ A}$$

$$I_1 R_1 = 1.875 \text{ V}, I_2 R_2 = 0.75 \text{ V}, I_3 R_3 = I_4 R_4 = 0.375 \text{ V}, I_5 R_5 = 1.125 \text{ V}$$







8. In the left figure below, the first battery emf (i.e. its “voltage”) is $\mathcal{E}_1 = 10\text{ V}$ and the second battery emf is $\mathcal{E}_2 = 5\text{V}$. All resistors are $50\ \Omega$. (a) Find the current through and the potential difference across each resistor. (b) What is the power dissipated in each resistor? (c) What is the power supplied by (or perhaps consumed by?) each battery? Don’t forget to check that the sum of your answers for part b agrees with the sum of your answers for part c.

Wall outlets in a building supply **alternating current** (AC), whereas a battery supplies *direct current* (DC). My animation:

<https://youtu.be/0wgoPM13kIs>

Convention: black=hot, white=neutral, green/bare=ground.

$$V(t) = V_{\max} \sin(2\pi ft)$$

Wall outlets in a building supply **alternating current** (AC), whereas a battery supplies *direct current* (DC). My animation:

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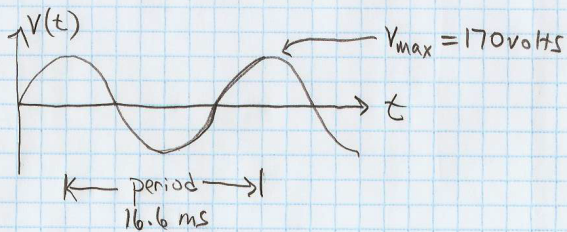
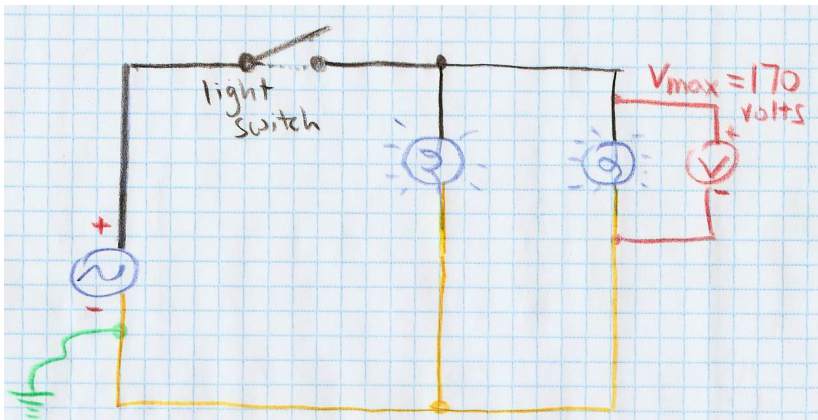
Convention: black=hot, white=neutral, green/bare=ground.

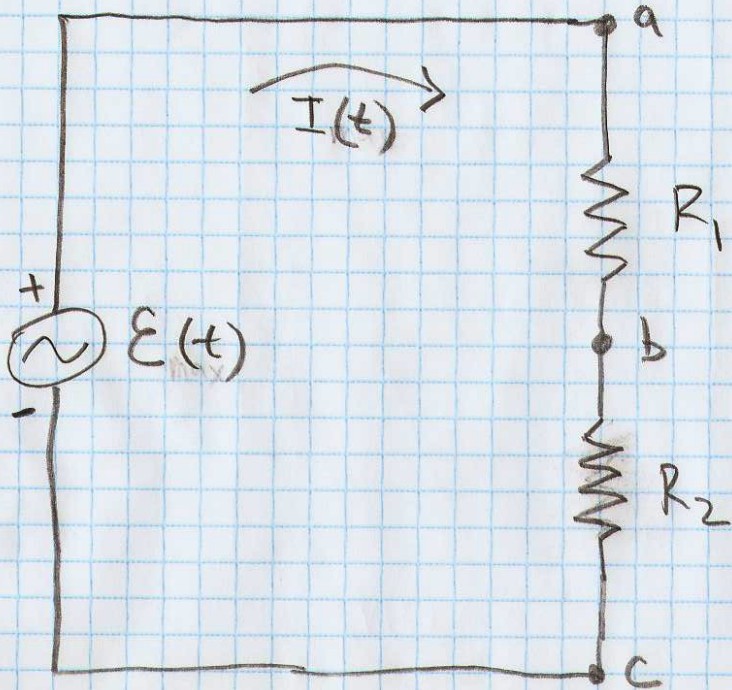
$$V(t) = V_{\max} \sin(2\pi ft)$$

$V_{\max} = 170$ volts, $f = 60$ hertz.

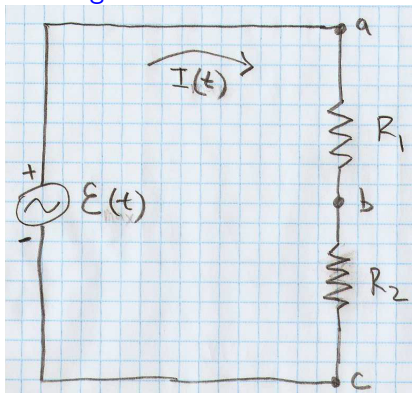
$$V_{\text{rms}} = \sqrt{\overline{V^2(t)}} = 120 \text{ volts}$$

(Remember that $\overline{\sin^2(\theta)} = \frac{1}{2}$ so $V_{\text{rms}} = V_{\max}/\sqrt{2}$.)





The usual “junction rule” and “loop rule” work for AC too, but voltage and current are functions of time now.



In series, each resistor (or light bulb) gets only a fraction of the total emf. So light fixtures are always in parallel, not in series (except holiday lights, etc.).

$$\mathcal{E}(t) - I(t)R_1 - I(t)R_2 = 0$$

Solving for current, we get

$$I(t) = \frac{\mathcal{E}(t)}{R_1 + R_2}$$

Voltage across top resistor is

$$V_{ba}(t) = I(t)R_1 = \frac{R_1}{R_1 + R_2}\mathcal{E}(t)$$

V across bottom resistor is

$$V_{cb}(t) = I(t)R_2 = \frac{R_2}{R_1 + R_2}\mathcal{E}(t)$$

If I plug a 60 watt light bulb into a standard household light fixture, what is the r.m.s. (root mean square) current that flows through the bulb?

- (A) 2.8 amps
- (B) 2.0 amps
- (C) 1.0 amp
- (D) 0.83 amp
- (E) 0.5 amp

If I use several “power strips” and several outlets to try to operate 100 separate 60-watt lamps simultaneously from the same (120 volt r.m.s.) household circuit, how much current (r.m.s.) flows through the fuse or circuit breaker that protects this circuit?

- (A) 0.5 amp
- (B) 5 amps
- (C) 50 amps

What is the r.m.s. current drawn by an 1800-watt hair dryer, operating from a standard 120-volt (r.m.s.) household outlet?

- (A) 1.5 amps
- (B) 10 amps
- (C) 15 amps
- (D) 25 amps

A typical U.S. house uses about 1000 kWh per month, i.e. on average about 1400 watts, or about 12 amps (at 120 V).

This varies a lot with season and time of day. So a typical U.S. house has 200-amp service coming in from the street, i.e. capable of 24000 watts, in case you have electric stove, electric water heater, clothes dryer, A/C, hair dryer, etc., all running at once.

Imagine that 500,000 homes in Philadelphia are using 20 amps (r.m.s.) each one evening. That's 1.2 gigawatts, which is about what a typical gas/coal/nuclear power plant generates.

At 120 volts, the total current from the power station to the city would be 10^7 amps.

In a copper wire of 1 cm radius, the voltage drop after just 2 kilometers ($R \approx 0.1 \Omega$) would be $IR \approx 10^6$ V.

What if the power were instead transmitted at a much higher voltage, like 100 kV ?

Copper wire: 1 cm radius, 2 km length would have $R \approx 0.1 \Omega$. We want to send 10^9 watts to Philadelphia. What if the power were transmitted at 100 kV instead of 120 V ?

Need “only” 10,000 amps: $(100 \text{ kV})(10 \text{ kA}) = 1 \text{ GW}$.

Voltage drop on 2 km copper wire is then $IR = 1 \text{ kV}$, which is only 1% of the voltage put out by the power plant. So only 1% of the plant's power is wasted in heating up the transmission line.

Power delivered is IV — that's current times voltage. The power wasted in heating up the cable is $I^2 R_{\text{cable}}$. So to deliver high power over long distances, we want to keep I as small as possible while keeping the product IV large. So very high voltages are used for long-distance power distribution.

How can you convert from (high current) \times (low voltage) into (low current) \times (high voltage) and back? A transformer!

Transformer: it only works with AC, not DC!

$$\mathcal{E}_S = N_S \frac{d\Phi_B}{dt}, \quad \mathcal{E}_P = N_P \frac{d\Phi_B}{dt} \quad \Rightarrow \quad \frac{\mathcal{E}_S}{\mathcal{E}_P} = \frac{N_S}{N_P}$$

Primary winding

N_P turns

Primary current
 I_P

+

Primary voltage
 V_P

-

Secondary winding

N_S turns

Secondary current
 I_S

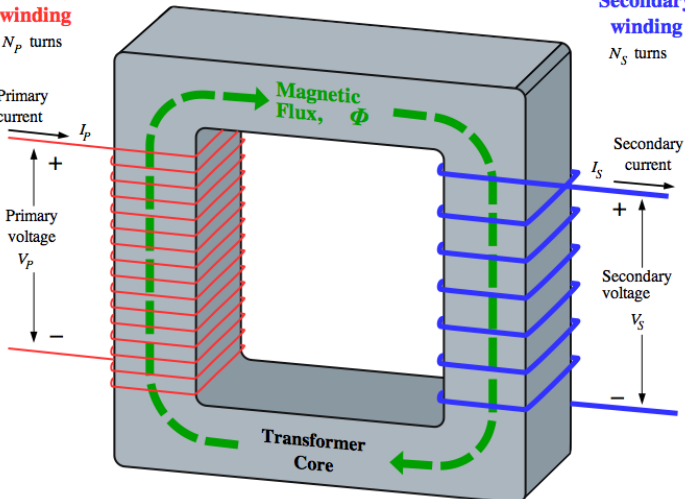
+

Secondary voltage
 V_S

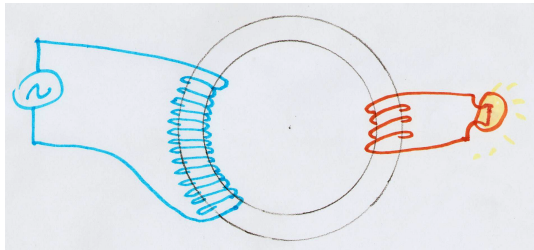
-

Magnetic Flux, Φ

Transformer Core

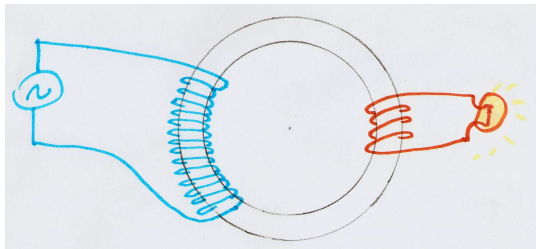


Consider an ideal step-down transformer in which the primary coil has 1000 turns and the secondary coil has 100 turns. The primary is connected to an AC power source, and the secondary is connected to a light bulb. If the rms voltage delivered by the AC power source is 120 volts, what is the rms voltage across the bulb?



- (A) 1.2 volts
- (B) 12 volts
- (C) 120 volts
- (D) 1200 volts

Consider an ideal step-down transformer in which the primary coil has 1000 turns and the secondary coil has 100 turns. The primary is connected to an AC power source, and the secondary is connected to a light bulb. If the rms current delivered by the AC power source is 0.1 amp, what is the rms current through the bulb?



- (A) 0.01 amp
- (B) 0.1 amp
- (C) 1.0 amp
- (D) 10 amps

Hint: the **power** on each side of an ideal transformer is the same.
 $P = IV$.

I'm interested in your opinions on the future of Physics 9. You may want to type your answers now and then paste them into your course review (or email them directly if you prefer).

- ▶ I like the course topics: briefly review forces, then cover waves, acoustics, light, fluids, heat/atoms, electricity/circuits.
- ▶ Which course topics do you think students will benefit from seeing more of or less of in future years?
- ▶ If you took Physics 8, please discuss the pros and cons of potentially merging Physics 8 and 9 into one semester, and how to do it.
- ▶ Which readings did you find most/least informative or interesting?
- ▶ Richard Farley and I are planning to write up some of our own materials with the aim of eventually replacing a decent fraction of the existing textbook material. We would explain the key ideas and the key equations, and we would include relevant anecdotes from Richard's decades of experience as a practicing architect. We might as well start with the topics for which you find the existing reading to be most lacking — so please do tell us where to begin! (Unifying themes: environmental systems, bldg construction, sustainability.)
- ▶ This year we added the brief coverage of Newton's Gm_1m_2/r_{12}^2 (satellites, etc.), since it wasn't in Physics 8.

- ▶ I intended also to include the “pseudo forces” that one experiences in non-inertial frames, e.g. inside a shaking skyscraper, and the “centrifugal” and “Coriolis” fictitious forces one experiences in a rotating frame. I think next time we actually will do it, briefly.
- ▶ We'd really like to include some computer-based exploration/simulation of architectural acoustics and of heating/cooling a space. Maybe other topics as well. Ideally we would do this in a way that does not require elaborate software installation.
- ▶ We included a bunch of hands-on activities last time, but this year's class size made that difficult this year. Perhaps we should try harder to make that work in an auditorium?
- ▶ A key goal is that with a bit more adjustment, we can make Physics 9 as much fun as Physics 8 is!
- ▶ For the 2/3 of you who were not in Physics 8 last year, we will offer Physics 8 again next fall. We cover Newton's laws of motion, thoroughly and from a different perspective than you saw in high school. Then we spend about a month applying Newton's laws to Architectural Structures.

- ▶ Teaching this course (4× so far) — discussing physics with you in person and by email, and working on solving physics problems with many of you — has been the most fun part of my career so far. Doing this job doesn't feel like “work.”
- ▶ We make this course as interactive as we can, so that we can adapt it to your interests, your questions, your learning styles. Your feedback has made this “your” physics course — more so than “mine.” What we've learned from you will help to make this a better course for future students.
- ▶ We've tried to push you to learn as much as you reasonably can about the physics we think will inform your intuition about the physical world in which your own creations will reside.
- ▶ My goal in teaching is mainly to be a good “coach.” Like other coaches, I can point you in the right direction, and offer help when you get stuck, but I can't do the learning for you.
- ▶ It has been a great honor to study physics with you this fall! Best wishes on your exams/reviews and in your careers!

Physics 9 — Monday, December 10, 2018

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