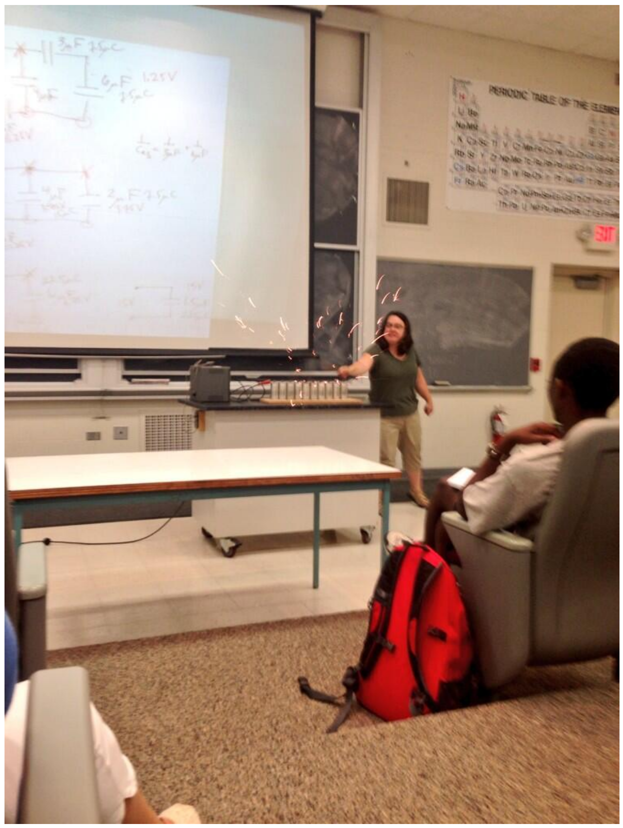
Sample Oral Exam Questions

Dan Styer, Oberlin College Physics Department

Whenever a numerical question is asked, it is understood that a single significant digit is desired.

Capacitor Discharge. In one spectacular physics demonstration, the rapid discharge of a capacitor bank results in a bang and a flash of light.



The capacitor bank is made up of 10 capacitors in parallel, each with a capacitance of 900 μF. Before the discharge, the bank was charged with a power supply to 25 V.

(a) About how much energy was discharged? (b) If all of the energy discharged went to visible light (it didn't, there was certainly sound and infrared photons), about how many photons were produced? (Question posed by Jennifer Hampton, Hope College, at Oberlin College 2018 exams.)

First solution to part (a): Capacitors add in parallel, so the total capacitance is $10 \times 900\ \mu\text{F} = 9$ mF. Thus the capacitor energy, all of which is discharged, is

$$E_c = \tfrac{1}{2} C \Delta V^2 = \tfrac{1}{2}(9 \times 10^{-3}\ \text{F})(25\ \text{V})^2 = \tfrac{1}{2}\, 9 \times 10^{-3} \left(\frac{100}{4}\right)^2 \text{J} \approx 4 \times 10^{-3} \frac{10^4}{4 \times 4} \text{J} = 2.5\ \text{J}.$$

Second solution to part (a): What if you can't remember that capacitor energy is given by $\frac{1}{2}C\Delta V^2$? Then use dimensional analysis. The energy must be some function of C and of ΔV. The unit of capacitance is the coulomb/volt, the unit of potential difference is the volt, a volt is a joule/coulomb. The only way to combine these quantities to make something with the units of joule is as $C\Delta V^2$. This technique can't give you the factor of $\frac{1}{2}$, but it's *way* better than "I have no idea."

First solution to part (b): Perhaps you know that optical photons have energies of 2 to 3 eV. Then you're almost done.

Second solution to part (b): But perhaps you don't know this. You *do* remember that the energy of one photon is $E_p = hf$, but off the top of your head you don't know a typical optical frequency (most physicists don't) and you don't know the value of h in SI units (most physicists don't). However you do know that for any EM radiation, $f\lambda = c$, and you do know that a typical optical wavelength is a few hundred nanometers. Thus

$$E_p = \frac{hc}{\lambda}$$

and you also know, from your *Modern Physics* course, that $hc = 1240 \text{ eV}\cdot\text{nm}$. So use light of wavelength 500 nm, giving E_p about $\frac{10}{4}$ eV.

Third solution to part (b): But maybe you can't remember the combination $hc = 1240 \text{ eV}\cdot\text{nm}$. Don't panic. Perhaps you remember that at room temperature a typical thermal energy is $k_BT = \frac{1}{40}$ eV, and that objects at room temperature glow in the infrared, whence an IR photon has energy of about $\frac{1}{40}$ eV. And perhaps you remember that the ionization energy for a hydrogen atom is 13.6 eV, and that this energy corresponds to an ultraviolet photon. (It certainly can't correspond to an optical photon. If optical photons had enough energy to strip the electron from hydrogen, it would endanger your life to walk out of a dark room.) Optical photons have energies between IR and UV photons, so they're in the ballpark of 2 or 3 eV. ⟦This solution relies on your knowing both a lower bound and an upper bound. If you only remember one of these two bounds, say that one and ask for a hint about the other.⟧

Fourth solution to part (b): Perhaps you remember looking at the Balmer spectral lines in lab: the beautiful red, aqua, and violet light emitted by hydrogen in a discharge tube. You know that these photons are *less* energetic that the ionization energy 13.6 eV, but not much less. Take a shot at about 2 or 3 eV.

Fifth solution to part (b): Perhaps you remember that at room temperature (300 K) a typical thermal energy is $k_BT = \frac{1}{40}$ eV. And perhaps you remember that when iron melts at a temperature of about 2000 K (actually 1811 K, but we want an estimate) it glows red. Then a typical thermal energy associated with glowing red is

$$\frac{1}{40} \text{ eV} \times \frac{2000 \text{ K}}{300 \text{ K}} = \frac{1}{6} \text{ eV}.$$

This estimate for the energy of a red photon is too low by a factor of ten, but it's infinitely better than "duhh. . . ".

Finish off part (b): All five of these methods give the photon energy in electron volts, but we found the capacitor energy in joules. The charge on a proton is 1.6×10^{-19} C, whence 1 eV $= 1.6 \times 10^{-19}$ J. Using the second estimate for photon energy, namely $\frac{10}{4}$ eV, gives the energy of an optical photon as $\frac{10}{4} \times 16 \times 10^{-20}$ J $= 4 \times 10^{-19}$ J. The number of photons is thus about 10^{19}.

Shirt. How many miles of thread are in that shirt you're wearing?

Answer: How big is a shirt? About 1 yard square = 36 inches on a side.

How dense are the threads? Lands' End advertises sheets of "200 threads per inch," and shirts are probably close to this as well.

Number of horizontal threads ≈ 200 threads/inch $\times$ 36 inches $= 200 \times 6^2$.

Number of horizontal and vertical threads $\approx 2 \times 200 \times 6^2$.

Length of each thread, according to assumption above = 36 inches.

$$\begin{aligned}\text{Length of thread in shirt} &\approx 2 \times 200 \times 6^4 \text{ inches} \\ &\approx \frac{2 \times 200 \times 6^4 \text{ inches}}{6000 \text{ feet/mile} \times 12 \text{ inches/foot}} \\ &= \frac{2 \times 200 \times 6^4 \text{ mile}}{2 \times 6^2 \times 1000} = \tfrac{1}{5} \times 36 \text{ mile} \approx 7 \text{ miles.}\end{aligned}$$

Notice there's no need to multiply $2 \times 200 \times 6^2$ threads to find 14400 threads. You're just going to divide that number by 6000×12, and it's easier to do the division if both numerator and denominator are already factorized. If you use a different shirt size or thread count, you will of course find a different answer, which would be equally correct — just make your assumptions clear. And of course, to use more than one significant figure in this problem would be an error too dreadful to contemplate.

Neon Sign. On the top of Mill Mountain, overlooking Roanoke, Virginia, stands the glowing neon "Mill Mountain Star". A plaque at the base of the star says it is "a symbol of the progressive spirit of Roanoke, star city of the South", and that the "current consumed" is "17,500 watts". What current is *really* consumed?

Answer: Zero amperes. Charge is conserved, so current is never "consumed". The plaque presumably means the power transformed into light and heat.

Magnetic Field Lines. How many magnetic field lines are there in the universe? (Question posed by Enrico Fermi.)

Answer expected by Fermi: Magnetic field lines neither begin nor end. In your introductory *Electricity and Magnetism* course you encountered "ideal" situations (like the infinitely long straight wire) in which magnetic field lines make circles, but in any real situation the field lines will not form perfect circles... instead the field line will run around and eventually, after tracing out the entire universe, it will arrive back where it started. The answer to this question is "one".

Rotation of Earth. At Oberlin, you toss a ball due south. After 2 seconds, it lands 30 meters away. Does it land due south of the tossing point, east of due south, or west of due south? How far east or west? (The latitude of Oberlin is 40 degrees north, and the radius of the Earth is 6400 kilometers, but you don't need either for an approximate solution.)

One possible solution: I don't carry the Coriolis effect formulas around on the top of my head. But I do keep track of the qualitative source of the effect: As the Earth rotates, the tosser and the target are both moving from west to east. But the target is closer to the equator so it's moving *faster*. So the qualitative answer is west of due south.

The exact formula involves a cross product, and hence the sine of an angle related to latitude, but as I said I can't remember it. I get an approximate formula by noting that the rotational velocity of the Earth's surface at the north pole is 0, whereas at the equator it is $2\pi R_E/(24 \text{ hr})$. If the increase in rotational velocity moving from pole to equator (a distance of $\frac{1}{2}\pi R_E$) were linear, then the rate of increase would be $4/(24 \text{ hr})$, independent of R_E! The deviation is thus

$$\begin{aligned} & \frac{4}{24 \text{ hr}} \times \text{distance of flight} \times \text{time of flight} \\ = & \frac{1}{6 \text{ hr} \times 60 \text{ min/hr} \times 60 \text{ s/min}} \times (30 \text{ m}) \times (2 \text{ s}) = \frac{1}{360} \text{ m} \approx 3 \text{ mm}. \end{aligned}$$

Rail Yard. A rolling 31 ton railroad boxcar collides with a stationary flatcar. The coupling mechanism activates so the cars latch together and roll down the track attached. Of the initial kinetic energy, 38% dissipates as heat, sound, vibrations, mechanical deformation, and so forth. How much does the flatcar weigh? (Dan Styer's favorite.)

Answer: 19 tons.

Galactic Journey. Veronica journeys from one edge of our galaxy to the other — 100,000 light years — while aging only 10 years. How fast was she traveling?

Answer: $V/c \approx 1 - \frac{1}{2}10^{-8} = 0.999\,999\,995$.

Mountain View. The view from atop Mount Holyoke in Massachusetts (elevation 878 feet) is justly famous. Thomas Cole painted this summit view in his 1836 landscape "The Oxbow," which hangs today in New York's Metropolitan Museum of Art. Whereas Glacier Point in Yosemite National Park provides a famous a wilderness view; Old Rag in Shenandoah National Park provides a famous pastoral view; and the Empire State Building in New York provides a famous urban view; the view from Mount Holyoke mixes all three of these elements in a sublime way that shows humanity and nature in harmony, rather than in conflict. Indeed, on an exceptionally clear day from the summit of Mount Holyoke you can see the skyscrapers of Hartford, Connecticut — 37 miles away — etched against the horizon. What is the radius of the Earth?

There are thousands of good oral exam questions of the form **"draw a graph and explain its features physically."** See for example D.F. Styer, "Specific Heats of Model Gas Molecules: An Oral Exam Teaching Strategy," *American Journal of Physics* **65**, 974–978 (1997).

A good way to prepare for an oral exam (indeed, a good way to prepare for a physics career) is for several students to get together and think up questions like these.