Exam 2; Phys 186 Name ______________

You can pick up your graded exam either later today (I'll be here grading), or in my office between 11:00 and 12:00 Friday May 9.

Note: As I walk around, you can ask me for help; for example, to supply an equation or a number you have forgotten down, or to give you algebra aid. If you do, however, I will write down what help I provided on your exam, and grade your answer accordingly.

1. (30 points) We characterize waves by their frequency, wavelength, and amplitude. Audible sound has a frequency range of 20 Hz to 20 kHz, wavelengths between 1.7 cm and 17 m, and a minimum intensity of 10^{-12} W/m^2. *Ultrasound* can be used for medical imaging, where it can resolve structures with sizes considerably less than 1 cm. The "ultra" in ultrasound must therefore refer to higher than audible frequency, wavelength, or amplitude—which one? Explain. For the range of values in question, you can take the speed of sound to be constant.

2. (30 points) Here is an annoying quotation from a "quantum healing" web site:

> . . . to live healthier and longer . . . you can use the wave-particle duality from quantum physics. First, you use waves produced by your neuron vibrations. When you have an experience, e.g. saying a prayer for your loved one who is ill, relevant neurons in your brain vibrate in unison at similar frequency. These vibrations unify your deepest desire, emotion, intelligence and spiritual strengths that you can use for healing. Even though you are physically separated from your loved one, visualize that quantum fields can bring your vibrations into relationship between both of you.
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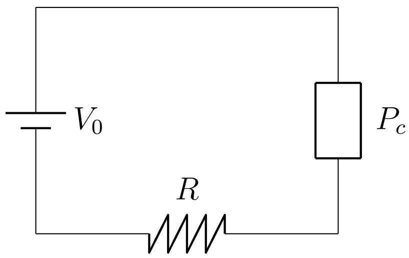
> Second, you use boson particles. When two systems interact, they exchange bosons. We can say that bosons are particles of relationship. Bosons can merge and become one entity. When you and your partner desire for healing, visualize that both of your bosons merge to achieve the synergistic healing.

(a) Briefly explain wave-particle duality, and point out what is wrong with the quotation.

(b) Briefly explain the quantum picture of interactions, and point out what is wrong with the quotation.

3. (30 points) There have been occasional concerns that people living close to electric power lines might have high risks of cancer due to their proximity to electromagnetic radiation emitted by the power lines. Determine, using a simple calculation, whether this concern is warranted. I will supply any physical data that you need—just ask me. I'm interested in whether you know to ask the right questions about the numbers that you might need.

4. (30 points) Electric power transmission lines are set up to minimize resistive power losses over long distances. Here is a simplified model of a circuit with a power plant, power lines, and a city consuming power. The power plant is a battery, which supplies a voltage V_0 and puts out a current I_0. The power lines are a fixed resistance R. And we will represent the city as a device that simply consumes a constant power, P_c.



(a) The power supplied by the battery is $P_0 = V_0 I_0$. Show that this is so, using the relationship of voltage to charge q and energy difference ΔU_E, and the relationship of current to charge q and time Δt.

(b) In the circuit above, the power supplied by the battery is $P_0 > P_c$. Show that the power lost to dissipation by R becomes smaller as V_0 becomes larger. Hence power lines operate at very high voltages to minimize the loss.

5. (30 points) Students doing a radiation lab do a long-time measurement of the average background radiation, and find 1.2 counts/second. They then place a sample of an α-emitting isotope by their detector for a long time, and record an average of 24.2 counts/second. Exactly a year later, another group of physics students perform the same lab. They again find 1.2 counts/second as the background. And when they use the exact same α-emitting sample in the same way, their detector gives 8.7 counts/second as the activity. What is the half-life of this isotope?

6. (50 points) The diameter of a proton is about 10^{-15} m. But the proton is not an elementary particle: it is three quarks bound by the strong nuclear force. The strong nuclear force is such that quarks very close together behave as if they are free—the force becomes negligible. But if the quarks move further apart than about the size of the proton, the strong force becomes huge. In other words, quarks are in a situation similar to being confined to a box (like a quantum dot). The mass of each quark is about 2 MeV/c^2, which is much smaller than the mass of a proton, 938 MeV/c^2. The large difference must mean that most of the mass of a proton is due to the energies of the bound quarks and $E = mc^2$! To see this, let's estimate the mass of the proton.

(a) Estimate p, the magnitude of the momentum of one of the quarks that make up a proton. *Note:* If you have a probability distribution $\mathcal{P}(z)$ for an arbitrary variable z, with standard deviation Δz, a good estimate for the average value for $|z|$ is Δz.

(b) Using $p = mv$ and your estimated p, calculate the speed v of the quark. Look carefully at this value. Does this mean that you should use the nonrelativistic expressions for the kinetic energy and momentum, $K = p^2/2m$ and $p = mv$, or the relativistic expressions $K = (\gamma - 1)mc^2$ and $p = \gamma mv \approx \gamma mc$ with $v \approx c$?

(c) Using your chosen equations for p and K, estimate the energy of a quark in the proton.

(d) Finally: there are three quarks in a proton. Estimate the total energy, and therefore the mass, of the proton. Compare your result to 938 MeV$/c^2$—you won't be exact, but your estimate should have the right order of magnitude (be within a factor of 10).