PHYS 212 James Scholar Assignment #1

The problems are to be done on paper, **showing all work**. Again, *the presentation should be neat, legible, and easy to follow*.

Each page of your submission must contain: your name, discussion section, netid, and the assignment number

This assignment must be submitted to Gradescope by 5 pm on the due date.

If you are reading this, then you are probably a James Scholar who is taking Physics 212 for Honors credit. To earn James Scholar credit for Phys 212, you will be asked to complete five extra mini-assignments. They are not intended to be long and shouldn't take more than an hour or two (however, you should definitely work on them in advance in case you get stuck and need to ask for help). The goal is to give the Honor students a slightly deeper look at some of the applications of the material of Phys 212. The type of assignment will vary. Sometimes, we will ask you to solve one or two E&M problems related to 'the real world'. Other times, you will be asked to explain how something works. Still other times, you will be asked to do research on a particular topic and write a paragraph or two summarizing your findings. For the latter tasks, we encourage you to access the web, other textbooks, or other articles you may find. The use of 'generative AI' such as ChatGPT for any of these assignments is not permitted. All writing tasks should be free of spelling and grammatical errors. The problems are to be done on paper, showing all work. **Again, the presentation should be neat, legible, and easy to follow.** Your assignments will all be submitted using Gradescope. Assignment deadlines and the Gradescope access code can be found on the James Scholar page

Text assignment: Using the web, textbooks, or other articles, explain the phenomenon of "triboluminescence," emphasizing the role of electrostatics.
(You should use no more than one-third of a page.)

The following problems are to be done on paper, **showing all work**. *The presentation should be neat, legible, and easy to follow.*

What is the "self-energy" of the electron? (Don't be scared by all the text – the calculation is not too difficult, though the result may be …unsettling.)

Calculation 1: Pretend the electron is made up of two halves, each with charge e/2. How much energy is required to bring the two halves together, i.e., so that they occupy the same point in space?
Calculation 2: That calculation was a bit over-simplified. Let's do a better job. Pretend that the charge of an electron is spread uniformly over the surface of a spherical shell with radius r_0. Next, calculate the electric field everywhere in space, i.e., at an arbitrary distance r from the center of the shell. Obviously, the answer will depend on r and r_0. Next, calculate the total energy stored in the field, by integrating the energy density **u** over all space. Finally, let the "electron" become a point particle, by letting r_0 go to zero.

What does it all mean??! (For your reading enjoyment, and cultural enrichment)

If the answers you got for this problem bother you, they should. It bothered (and still does bother) physicists for several decades. It's easy enough to dismiss the first calculation – if the electrons really are indivisible particles, then we don't need to worry about "assembling" them. However, the second calculation is more troubling. Can the energy stored in the field of every electron be that big?! In a classical model of the electron there seems no good way around this problem.

Quantum mechanics helps …sort of. The first mitigating fact is that empty space – vacuum – is actually very lively, with electron-positron pairs simply popping into and out of existence all the time (a positron – the antiparticle of the electron – is just like an electron, with the same mass, but the opposite charge). We use the term "virtual" to describe such particles that only exist momentarily. You might find this unbelievable, but the consequences are observed all the time in high-energy particle physics experiments. What is the effect of these virtual electron-positron pairs? You can think of them as tiny electric dipoles (which pop into existence for less than 10^{-20} seconds). What is their effect on the electric field of the original electron (let's call that one "Fred", to avoid confusion with the virtual electron)? A simple model is that the positron is attracted toward the electron Fred, and the virtual electron is repelled. That means that electric field from the positron will partially cancel that of the electron Fred. This is exactly the same thing that happens when we put a dielectric in between two capacitor plates with a fixed charge on them – the dipoles in the dielectric align up with the electric field and reduce it. Looked at another way, when the virtual positron is near the electron Fred, some of the field lines that come from Fred now end on the positron. This screening effect reduces Fred's electric field.

When we measure the actual charge of the electron, we measure its field at a large distance r away and say that that the field is e/r^2, and thus determine e. In fact, we are measuring the field due to the "bare electron" plus the field reduction due to all the extra stuff popping into and out of existence in the vacuum. Unfortunately, this field reduction looks like a reduction in the charge of the electron by an infinite amount! Now what?! Theoretical physicists found a trick to deal with this problem, with the complicated name of "renormalization". It is appropriate that the name is complicated because the procedure is also complicated, and for a while, many physicists thought it was a swindle. (Eventually, physicists came to believe it, and a few Nobel Prizes were given out.) Since the purpose of physics is to be able to make definite predictions about specific physical systems, one can make sense of this calculation by saying that the electron starts with an infinite "bare" charge, and, well, infinity minus infinity is just the finite charge that we measure, the one that's listed in the books.

A similar problem occurs when we try to calculate the total energy of the electron and field, and hence, from Einstein's $E=mc^2$, the mass of the electron. The total effect of the virtual pairs is to reduce the electron's energy by an infinite amount. Again, we have to start with an infinitely large "bare mass," and again, infinity minus infinity is just the finite mass that we measure, 10^{-31} kg.

This is the basic trick of renormalization theory – just subtract off the infinities. If this sounds like cheating, you should know that even Richard Feynman, one of the physicists who figured this out, describes it as "a loopy process"!

There's one more problem. Einstein said that $E = mc^2$, which states that energy and mass are, in some sense, equivalent. Just like mass, energy is affected by - and also creates –

gravitational fields. So, if we have infinite energy, does this mean we have infinite gravity? Clearly, we do not (or the universe would not exist). But the resolution is still largely an unsolved problem. No one has successfully united the theory of gravity with quantum mechanics, and this is one of the Big Unsolved Mysteries in physics.

One "solution" might be to say that we really can't expect our physical laws to be the same at extremely short distances (where by "extremely short," we might mean less than 10^{-35} cm. People believe now that space itself is no longer smooth at these tiny distances but instead is "grainy" and that this graininess might somehow explain the paradox of the electron self-energy. Certainly, this is one of the deepest and least understood areas of modern physics – what is the true nature of space and time?!