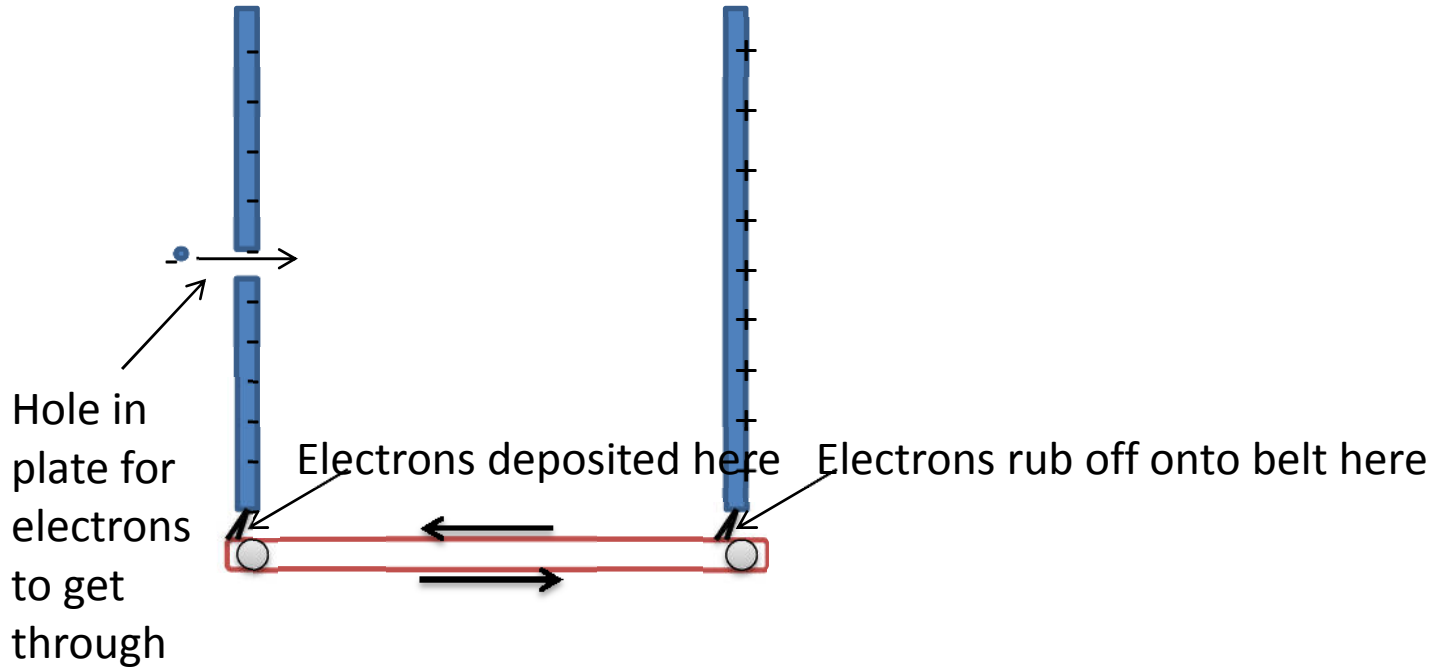
Problem Set 4

Problem 1

For both particle physics research and everyday applications (e.g. old TV sets), it is useful to be able to accelerate charged particles to high speed. The simplest way to achieve this is to set up a constant electric field between charged plates and then accelerate an electron in these fields. One way to do this (employed in some of the first particle accelerators known as van de Graaff accelerators), would be to set up a belt that can rub off electrons from one plate and deposit them on another plate.

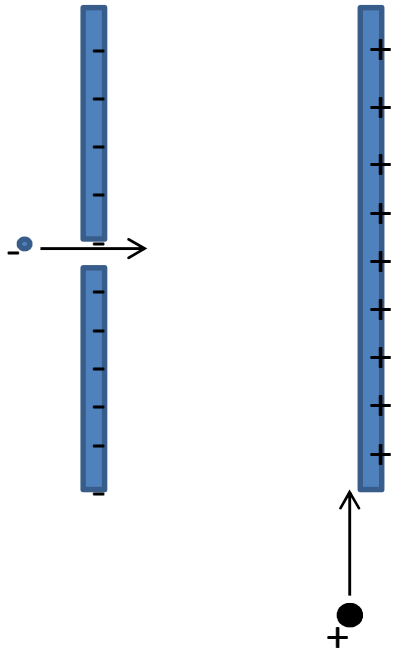


a) Suppose the plates have area A and the distance between the plates is d. If we want to be able to accelerate an electron to speed v by the time it reaches the far plate, how much charge to we need to take from one plate and deposit on the other plate? *(Hint: you can start by using energy conservation to determine what potential difference would we need to have between the plates.)*

b) For the configuration of charged plates in part a) find an expression for the ratio Q/V, where Q is the amount of charge on each plate and V is the potential across the plates. This ratio is called the capacitance C. What types of variables does the capacitance depend on? What can you do to increase the capacitance?

c) If the plates are squares with area $1m^2$ and the separation is 0.1m, what charge do we need if we want the electron to be travelling at half the speed of light? *(Hint: do you need to adjust any of your formulae from part a to account for the relativistic speed?)*

d) Suppose that we set up the plates (which have the same geometry as in part b) so that the electron will be travelling at 10^6m/s (much less than the speed of light) by the time it reaches the middle of the plates (starting from zero velocity). If we send in a proton as shown, what initial speed v does the proton need to have (in the vertical direction), and at what time should we send it in (relative to when the electron is inserted) so that it will collide with the electron right in the middle of the plates? (*Hint: you will need to figure out the proton's trajectory for a general speed v and the pick the speed so that the trajectory passes through the middle.)*



Problem 2

Suppose we have a very dilute gas of electrons with density n in empty space. At some time, a uniform electric field E is turned on. What is the current of electrons through an area A perpendicular to the field as a function of time? Explain why this is different than the current in a wire, which is typically constant in time for a fixed electric field?

Bonus Problem 1 : Haggis potential

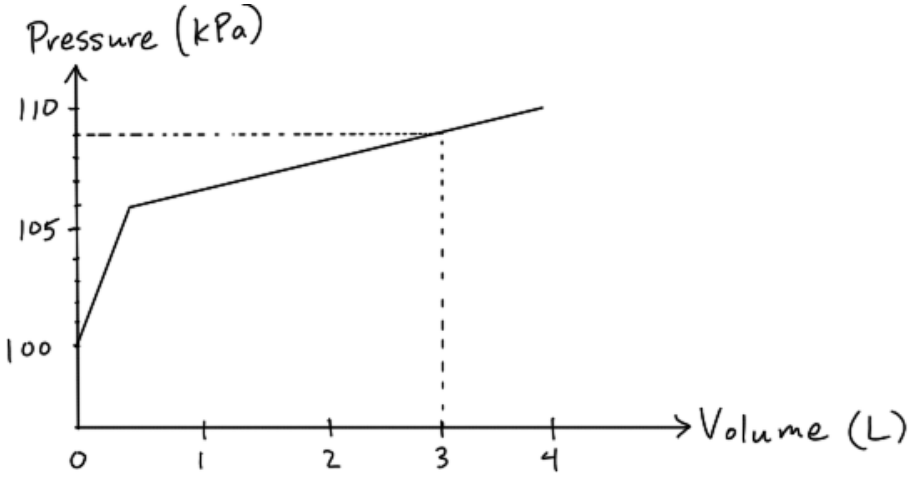
A spherical haggis of radius R has a total charge Q uniformly distributed throughout its volume. Determine the electric potential at the center of the haggis, if the potential at infinity is defined to be zero.

Bonus Problem 2: Deflategate!

One Sunday afternoon at Colette's 9th birthday party, Colette and her friend Patty inflate some balloons for a game of Balloon-Frenzy. Patty's team wins easily, even though Colette is usually really good at Balloon-Frenzy. Later, Colette discovers that the pressure inside Patty's team's red balloons was 1kPa less than the usual pressure for Balloon-Frenzy, which might have given Patty's team an advantage. Furious, Colette calls up Patty and accuses her of deliberately underinflating the balloons, thus ruining her entire birthday. Patty says she has no idea what Colette is talking about, and that she and her team inflated the balloons to the same size as Colette's team. But then Patty remembers that she and her teammates were rubbing the balloons on their hair and sticking them to the wall after inflating them. She suggests to Colette that maybe this somehow resulted in the decreased pressure inside. Colette says that Patty's story is the silliest thing she's ever heard, and to prove it, she's going to ask her older sibling (you) who just happens to be an expert in physics.

a) Could rubbing a balloon on your head (and thus adding charge to the surface) lead to a decrease in pressure? Explain. Assume that the friction does not lead to a significant increase in temperature of the gas.

b) If Patty's story is true, how much charge would have to be on the surface of the balloon to explain a pressure decrease of 1kPa? The standard pressure of a balloon for a game of Balloon Frenzy is 109kPa, and the interior pressure vs volume for a standard balloon is shown below.



c) Do you believe Patty's story? Should Colette invite Patty to her next birthday?

Note: if you haven't been paying close attention to the media lately and feel that this may be the most random physics question ever, see: http://en.wikipedia.org/wiki/Deflategate