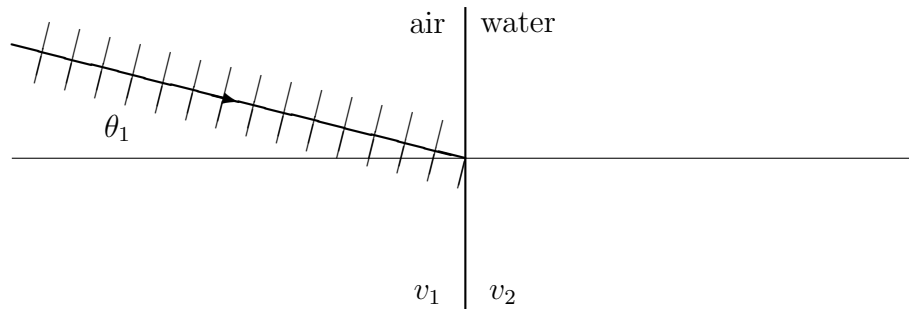


Note: You can ask me for help; for example, have me check if an answer is correct.

1. (30 points) You have a sound wave traveling from air into water.

- (a) Complete the following diagram on the water side. The parallel lines indicate wavefronts, while the line with an arrow is the direction of energy transfer. The speed of sound in air is v_1 , the speed of sound in water is v_2 , and $v_2 > v_1$.



- (b) What is the equation that gives the relationship between v_1 , θ_1 , v_2 , and θ_2 ? Explain your reasoning.

2. (40 points) Imagine that in the lab you had sources of “Q-rays.” You also have detectors indicating the intensity of incident Q-rays. There are two theories about Q-rays: (1) the source emits a stream of small, invisible, and extremely numerous Q-particles; (2) the source emits Q-waves.

You can test whether there are Q-particles by observing that particles can collide with each other, while waves just interfere. You set up two Q-beams whose paths cross, and see if there is any sideways scattering from the beam paths due to particles colliding. If so, that is strong evidence for particles. If, however, there is no scattering, it doesn't guarantee waves. After all, the particle size d might be very small, making collisions unlikely.

(a) Describe an experiment in which you can test for Q-waves. Explain its rationale: tell me what a positive result would be and why it would be strong evidence for waves.

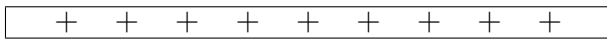
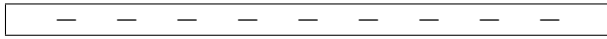
(b) Would a negative result in your experiment guarantee particles, or would some kinds of waves also give a negative result? Explain.

3. (40 points) Imagine a single-frequency electromagnetic wave (sine wave) going through an area in which there is an electron with initial position $x_e = y_e = 0$. Consider only the electric field: it points up and down (depending on what part of the sine wave is going through) along the y -axis, while the wave travels in the $+x$ -direction. At all times $E_x = 0$ and E_y is the same at all points along the y -axis. At time $t = 0$, at all points where $x = 0$, $E_y = 0$, and after a very small time ϵ passes, the positive part of the electric field moves in, so that $E_y > 0$ when $t = \epsilon$. The frequency of the electric wave is f , its speed is c .

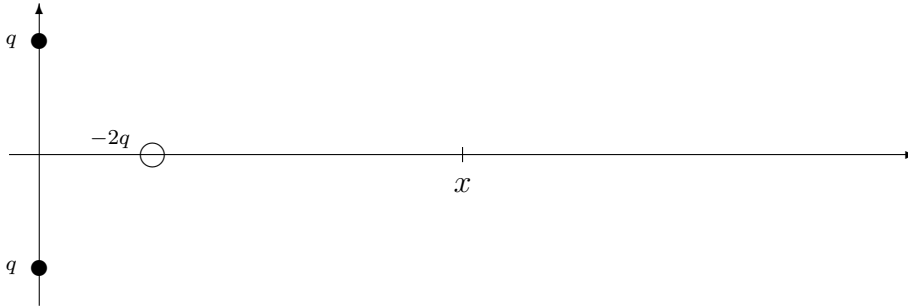
Make a qualitative graph of the electric force experienced by the electron, as a function of time t . Then make a qualitative graph of x_e and y_e vs. t . Explain your reasoning.



4. (30 points) Say you set up two finite metal plates and impose a 4V voltage difference between them, much like you did in your equipotential lines lab. For the following two plate arrangements, make qualitative drawings of the 0V, 1V, 2V, 3V, and 4V equipotential lines. Then add the electric field lines. Be sure to show what happens *outside* the plates.



5. (60 points) You have a charge distribution with point charges q at $x = 0, y = d$ and $x = 0, y = -d$, and a charge $-2q$ at $x = d, y = 0$. The positions of the charges relative to each other are fixed.



(a) Find the total electric field at a point a distance x from the origin on the x axis. In other words, find the total E_x and E_y as functions of k, q, d , and x .

(b) Find the total electric potential at the same point.

- (c) In class, we found that a dipole's electric field magnitude behaved like $E \approx km/x^3$ for $x \gg d$, where m was a constant. Find the electric field for this charge distribution when $x \gg d$, and show that $E \approx km/x^3$ in this case as well. Find m in terms of q and d for this charge arrangement.

You may use $(1 + \epsilon)^p \approx 1 + p\epsilon$ for $\epsilon \ll 1$. Also note that when $x \gg d$, $d/x \gg (d/x)^2$, which means you can neglect terms that go like $1/x^4$ when compared to terms that go like $1/x^3$. I'm available for algebra help.