UCLA Physics 1B

Practice Final Exam

Fall 2019, Version B

Spenser Talkington

1	/5
2	/5
3	/5
4	/5
5	/5
6	/10
7	/5
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15	/30
16	/20
17	/20
18	/15
19	/10
20	/10
Total	/200

Problem 1. (5 Points)

ESPN-LA broadcasts with 50 [kW] power at 710 [kHz] from 17.7 [km] North of campus. If the speed of light is 3×10^8 [m/s], what is the wavelength of the broadcast? (3 points) What is the intensity in [W/m^2] of the broadcast at UCLA? (2 points)

Problem 2. (5 Points)

What is the potential energy as a function of time for a spring-block system that starts at $t = 0$ with an initial velocity of 1 [m/s] away from equilibrium, at a location 1 [m] from equilibrium if the mass of the block is 1 [kg] and the spring constant is 1 [N/m]?

Problem 3. (5 Points)

Label each of the following as traveling, standing, or neither waves (1 point each):

- A diver at the bottom of Loch Ness shakes a communicate with their companions on the surface
- A FM radio station broadcasts Beethoven's 5th Symphony
- Saw dust piles up in specific patterns on a piece of plywood as it is shaken by a power tool
- A piano string resonates in its fourth harmonic
- Waves rippling outwards after a toddler throws a pebble in the center of a pond

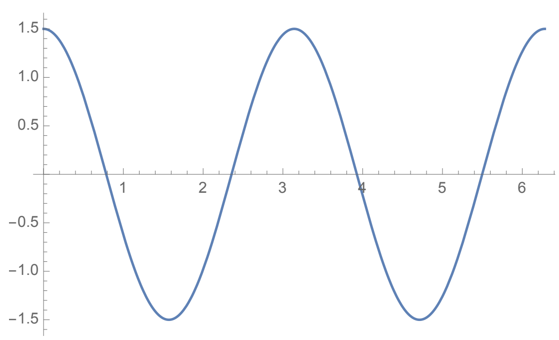
Problem 4. (5 Points)

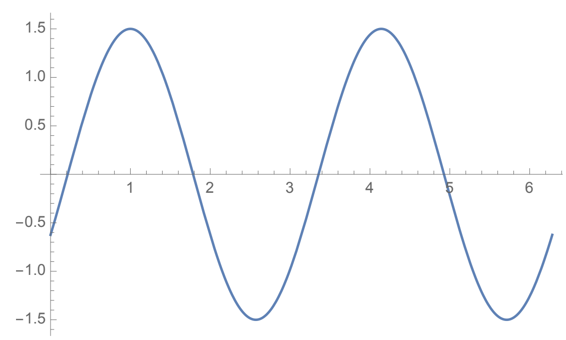
Is the speed of sound in water faster or slower than in air? (3 points)

What is the speed of sound in water? The bulk modulus is 2.2×10^9 [Pa], and the density is 1000 [kg/m^3]. (2 points)

Problem 5. (5 Points)

Find the position as a function of time, $x(t)$, given two images of a right-traveling wave taken at $t = 0$ and $t = 1$ respectively of a wave if the wave is given by $x(t) = A\cos(kx \pm \omega t + \phi)$.

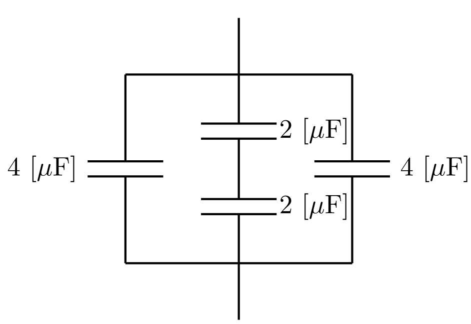


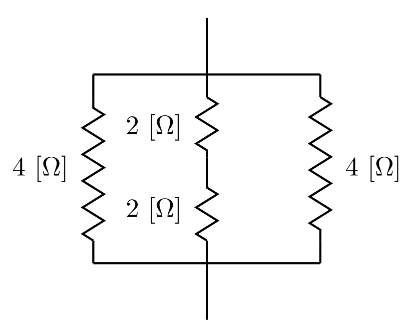


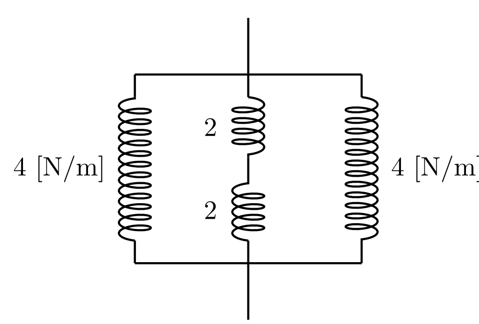
What are A, k, $\pm$, ω, and ϕ (1 point each).

Problem 6. (10 Points)

Determine the equivalent resistance (3 points), capacitance (3 points), and spring constant (4 points).







Problem 7. (5 Points)

Derive $T = 2\pi\sqrt{l/g}$ for a simple pendulum.

Problem 8. (5 points)

Suppose that an astronaut is diving into a pond of liquid ammonia on the surface of Venus. If the atmospheric pressure is 93 [bar], what pressure does the astronaut experience at the bottom of the pond if ammonia has a density of 730 [kg/m^3], if Venus has a gravitational attraction of 8.87 [m/s^2], and if the pond is 15 [m] deep.

Problem 9. (5 points)

The pyramid at Giza has a square base of side a and four faces which are equilateral triangles. The Scarab of Ra, buried at the very center of the base of the pyramid, has a net charge of Q. Do you know the net flux of electric field emerging from one of the triangular faces of the pyramid? If it can be determined, solve for the flux; if not, explain why.

Problem 10. (5 points)

Two conducting spheres of different radii are connected by a fine conducting wire. They have a net positive charge. Which sphere has more charge?

(a) The larger sphere
(b) The smaller sphere
(c) They have the same charge
(d) The answer depends on how the conductors were charged

Problem 11. (5 points)

Two insulated, identically charged spheres, suspended by strings from the same point are in equilibrium. An uncharged conducting plate is then placed underneath the spheres. After a new equilibrium is reached, the spheres will be:

(a) Closer together
(b) Further Apart
(c) In the same position as before
(d) Cannot be determined from the information given

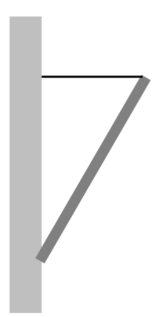
Problem 12. (5 points)

A sheet of charge of infinite extent is spread on the xy plane. At $z = 1$ the strength of the electric field is E. What is the strength of the electric field at $z = 100$?

(a) $10000E$
(b) $100E$
(c) E
(d) $E/100$
(e) $E/10000$
(f) 0

Problem 13. (20 Points)

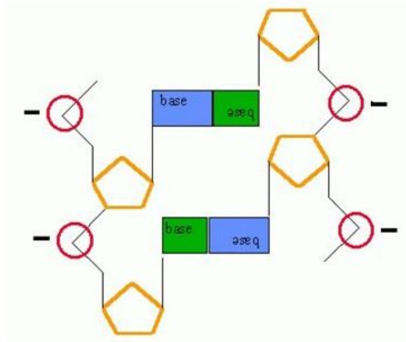
The lower end of a uniform bar of mass 45.0 [kg] is attached to a wall by a frictionless hinge. The bar is held by a horizontal wire attached at its upper end so that the bar makes an angle of 30 degrees with the wall. The wire has length 0.330 [m] and mass 0.0920 [kg]. What is the frequency of the fundamental standing wave for transverse waves on the wire? Hint: equate the torques at each end of the wire to find the force. Torque is $\boldsymbol{\tau} = \boldsymbol{r} \times \boldsymbol{F}$.



Problem 14. (10 Points)

We're going to make some major assumptions here, so brace yourself.

DNA is composed of two negatively charged PO_4^- groups surrounding two positively charged nucleotides, and with intermediate ribose groups.



Assuming that ribose acts as a dielectric with dielectric constant 60, and the separation of the positive and negative charges is 10^{-9} [m], find the voltage difference between a phosphate and an nucleotide. Note that the charge of an electron is 1.6×10^{-19} [C]. (4 points)

Find the capacitance of one base-pair (two nucleotides) and the two phosphate groups. (4 points)

Assuming the human genome is 3×10^9 base pairs, what is the capacitance of the human genome? (2 points)

Problem 15. (30 Points)

You come across a spherically symmetric electric field with the following form:

$$E(r) = \begin{cases} E_0 \left(\frac{r}{R}\right)^2 \hat{\boldsymbol{r}} & 0 \leq r \leq R \\ 0 & R < r \leq 2R \\ E_0 \left(\frac{r}{R} - 2\right) \hat{\boldsymbol{r}} & 2R < r \leq 3R \\ E_0 \left(\frac{3R}{r}\right)^2 \hat{\boldsymbol{r}} & 3R < r \leq 4R \\ 0 & 4R < r \end{cases}$$

(a) For all r, what is the charge $Q(r)$ contained within a radius r? (6 points)

(b) Calculate the charge density $\rho(r)$ everywhere. (6 points)

(c) Are there any surface charges in this charge distribution? If so, identify their location and give the magnitude of the surface charge density σ at each such location. (10 points)

The charge distribution is modified in some way. The new electric field is:

$$E(r) = \begin{cases} E_0 \left(\frac{r}{R}\right)^2 \hat{\boldsymbol{r}} & 0 \leq r \leq R \\ 0 & R < r \leq 2R \\ E_0 \left(\frac{r}{R} - 2\right) \hat{\boldsymbol{r}} & 2R < r \leq 3R \\ E_0 \left(\frac{3R}{r}\right)^2 \hat{\boldsymbol{r}} & 3R < r \leq 3.5R \\ 0 & 3.5R < r \end{cases}$$

(d) Compute the difference in energy between this and the old configuration, $U_{\text{new}} - U_{\text{old}}$. Was work done on the system or did the system do work? (8 points)

Problem 16. (20 Points)

In this problem, you will look at a circuit that contains a constant current source: the total current which comes out of this device is always I_0 no matter what EMF is required. The switch S is closed at $t = 0$. First, this source is hooked up to a pair of resistors in parallel as shown on the left.

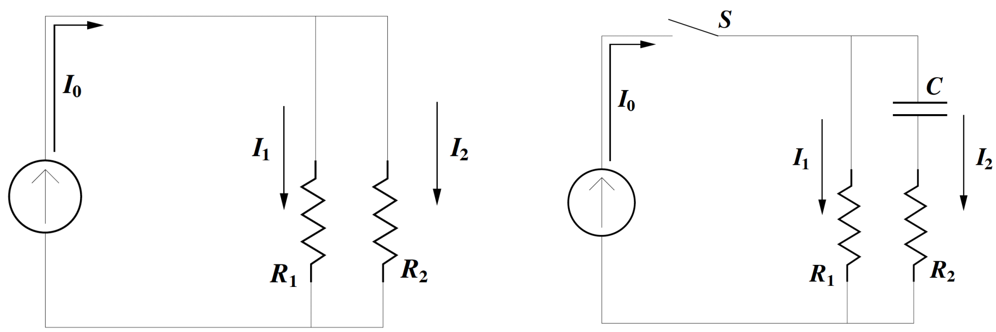
(a) Find the EMF E produced by the constant current source, as well as the currents I_1 (flowing through resistor R_1) and I_2 (flowing through R_2). (7 points)

The circuit is now modified: a capacitor and a switch are added as shown on the right. The capacitor is initially uncharged. The switch is closed at $t = 0$.

(b) Find the initial currents $I_1(t = 0)$, $I_2(t = 0)$, and the late time currents, $I_1(t = \infty)$, $I_2(t = \infty)$. You should be able to do this with very little calculation. (Express your answers in terms of I_0 and the parameters of the circuit). (3 points)

(c) Use Kirchhoff's laws to write down two equations relating $I_1(t)$, $I_2(t)$, I_0, and the charge on the capacitor Q. Write down a third equation relating Q to I_2. (7 points)

(d) Using the results of the last part, find the late time charge, $Q(t = \infty)$. (Express your answer in terms of I_0 and the parameters of the circuit.) (3 points)



Problem 17. (20 Points)

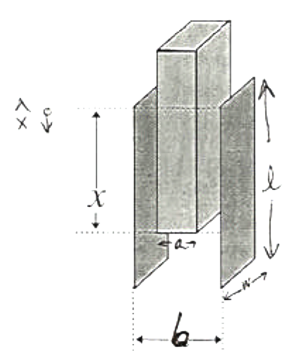
Consider a parallel plate capacitor with plate separation b and a sheet of metal thickness a. For this problem, consider the plates of the capacitor to be large enough so that fringing fields can be neglected.

(a) Does the capacitance of the capacitor rise of fall after the metal sheet is inserted between the plates of the capacitor? (3 points)

(b) If the capacitance of the capacitor before the metal sheet was inserted was given by C_0, what is the capacitance after insertion of the metal sheet? (6 points)

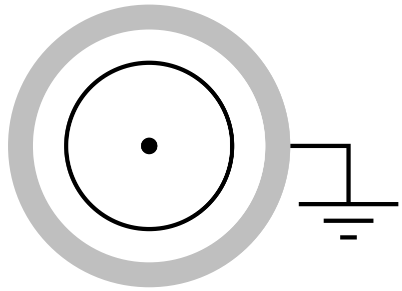
(c) Consider a charge of $+Q$ and $-Q$ placed on the plates of the capacitor. What is the energy stored in the capacitor before and after the metal plate is inserted between the plates? (6 points)

(d) Given the equation $F = -\partial U/\partial x$, where x is the length of the metal plate that is inserted between the capacitor plates, what is the force on the metal? (4 points) Which direction does it tend to move the metal plate? (1 point)



Problem 18. (15 Points)

Consider a point charge of magnitude $+q$ surrounded by a thin insulating shell of radius r_1 and total charge $-2q$, surrounded by a conducting shell of inner radius r_2 and outer radius r_3 that is grounded:



What is the charge on each face of the metal shell? (3 points each)

What is the total charge on the metal shell? (1 point)

What is the electric field in the regions $r < r_1$, $r_1 < r_2$, $r_2 < r < r_3$, and $r_3 < r$ (2 point each).

Problem 19. (10 points)

Suppose that water enters a tube of 20 [cm] diameter at UCLA (elevation of 96 [m]), and travels to the pier at Santa Monica, 10.4 [km] away. If the water starts at 1 [m/s], and experiences a drag so that it feels an effective force of $g = 2$ [m/s^2], how fast is it moving when it reaches the pier?

Problem 20. (10 Points)

Find the electric field at a point p on the z-axis generated by a disc of uniform surface charge density σ, and radius a.

Hint: the electric field in a given direction $\hat{\boldsymbol{n}}$ is $E_{\hat{\boldsymbol{n}}}\hat{\boldsymbol{n}} = (\boldsymbol{E} \cdot \hat{\boldsymbol{n}})\hat{\boldsymbol{n}}$.