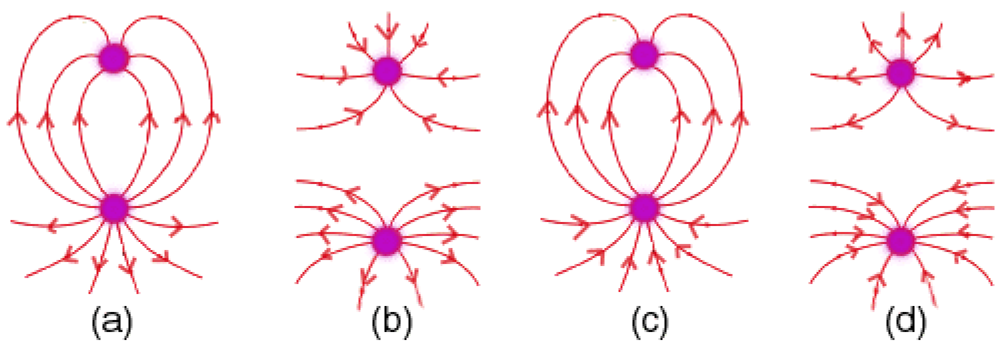
Physics 222 Final
August 7, 2002

$c = 3.0 \times 10^8$ m/s
$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/Nm^2
$e = 1.60 \times 10^{-19}$ C
$h = 6.63 \times 10^{-34}$ J s
$m_e = 9.31 \times 10^{-31}$ kg = 511 keV/c^2
$\mu_0 = 4\pi \times 10^{-7}$ Tm/A
1 light-year = 9.46×10^{15}m
$hc = 1.24$ keV nm

Each question is worth two points unless otherwise noted. Numerical answers may not match exactly. Choose the closest answer to the correct result.



1. **(a)** Which figure above shows the field lines for a positive charge $2Q$ and a negative charge $-Q$? (1 point)

(a) (b) (c) (d)

The field lines show the direction of force on a positive test charge, which would be repelled from the stronger chare and attracted toward the weaker one. Either (a) or (b) has this property, but only **(a)** shows the force in the correct direction.

(b) Which figure above cannot occur physically for a pair of charges? (1 point)

(a) (b) **(c)** (d)

All of the field lines from a point charge must point in the same direction, so **(c)** cannot occur.

2. Suppose you try to find the electric field outside a positively charged conducting sphere by measuring the force F on a positive test charge q and calculating F/q. Will F/q be bigger, smaller, or equal to the electric field E in the absence of the test charge?

(a) bigger **(b)** smaller (c) the same

The positive test charge will repel some of the positive charge on the sphere, which is free to move. This will cause the measured value of F/q to be **smaller** than the electric field E, which would be obtained only if q were infinitely small.

3. Suppose two identical parallel plate capacitors have equal charges. Capacitor A is connected to a battery, but capacitor B isn't. In which of these would it require work to insert a dielectric medium between the two plates?

(a) capacitor A (b) capacitor B (c) both capacitors (d) neither capacitor

For capacitor A, the voltage is fixed, while for capacitor B, the charge is fixed. Therefore, the energy of capacitor A is $U_A = ½\, CV^2$, while the energy of capacitor B is $U_B = ½\, Q^2/C$. Inserting a dielectric increases the capacitance C, which increases the U_A and decreases U_B. Therefore, inserting a dielectric in **capacitor A** is the only case that requires work.

4. If an electron gains 3.45×10^{-16} J of kinetic energy when accelerated from plate A to plate B in a computer monitor. What is the potential difference $V_B - V_A$ between plate B and plate A? Select the closest answer to the correct result.

(a) 20,000 V **(b)** 2,000 V (c) –2,000 V (d) -20,000 V

The change in kinetic energy is equal to the decrease in potential energy. Since electrons are negative, the potential energy decreases when the electric potential becomes more positive, so the answer must be (a) or (b). A numerical calculation gives $V_B - V_A = \mathrm{KE}/e = 3.45 \times 10^{-16}$ J / 1.60×10^{-19} C = **2.16 kV**, which is closest to **(b)**.

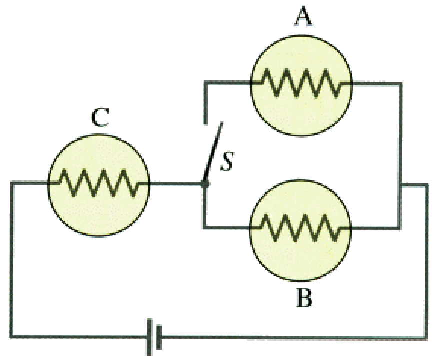
5. Which wire has the greatest resistance, assuming they are all made of copper?

(a) A 10 m long wire, 0.2 mm in diameter (b) A 45 m long wire, 0.5 mm in diameter

(c) A 5 m long wire, 0.15 mm in diameter (d) A 90 m long wire, 0.8 mm in diameter

The resistance is proportional to the length of the wire divided by the area, so it is proportional to L/D^2, where L is the length and D the diameter. Evaluating this ratio for choices (a) through (d) gives, respectively, 250, 180, 222, and 141 m/mm^2, so wire **(a)** has the greatest resistance, and wire (d) has the least.

6. Assume the switch S is initially closed, and then opened. Which bulbs would be brighter with the switch open? Assume all three bulbs are identical.

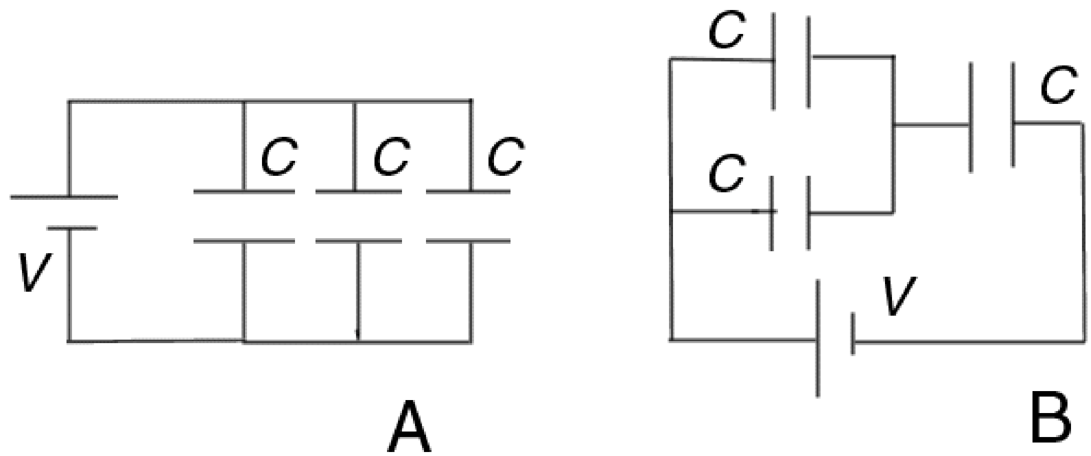


(a) B (b) C (c) C and B (d) none

The brightness increases if the current through the bulb increases. Assume each bulb has resistance R and the battery has voltage V. With the switch open, the same current flows through bulbs B and C, and no current flows through bulb A, so $I_B = I_C = V/(2R)$.

With the switch closed, the total resistance of bulbs A and B in parallel is $R/2$, giving a total resistance of 3R/2 for the three bulbs. Therefore, the total current from the battery is $2V/3R$. All of this flows through bulb C, and half through each of bulbs A and B, so $I_C = 2V/3R$ and $I_B = V/3R$. Comparing to the currents with the switch open shows that bulb **B is brighter** with the switch open, while bulb **C is dimmer**.

7.



Let U_A be the total electric energy stored in the capacitors in figure **A**, and U_B be the total energy stored in the capacitors in figure **B**. What is the ratio of U_A/U_B?

(a) 2.0 **(b)** 4.0 (c) 1.5 (d) 0.67

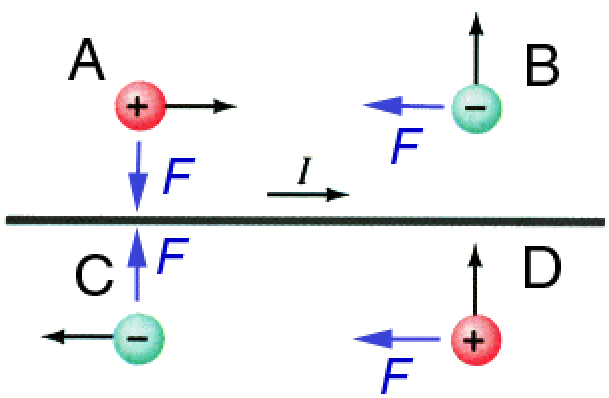
The energies of each set of capacitors are $U_A = ½\, C_A V^2$ and $U_B = ½\, C_B V^2$ where C_A is the total capacitance of the three capacitors in case A, and C_B is the total capacitance in case B. In case A, the total capacitance is $C_A = 3C$, while in case B, it is C in series with $2C$, which gives $C_B = (1/C + 1/2C)^{-1} = 2C/3$. Then $U_A/U_B = C_A/C_B = 9/2 =$ **4.5**. The closest answer is **(b)**.

8. Suppose negatively charged particles enter a region where the magnetic field is uniform and perpendicular to their velocity. How does the kinetic energy of the particles change?

(a) It increases. (b) It decreases. **(c)** It stays the same.

The force on a charged particle due to a magnetic field (in *any* direction) is always perpendicular to the direction of motion of the particle. Therefore, it does no work, and the kinetic energy **stays the same**.

9.

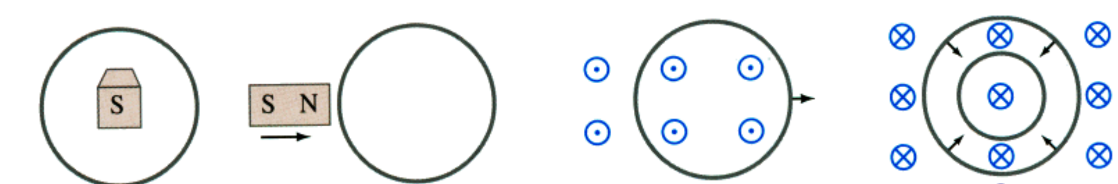


Four charges are moving near a current-carrying wire, in the directions shown. Which has a magnetic force acting *upward* on it in the illustration?

(a) A (b) B **(c)** C (d) D

The magnetic field points out of the page above the wire and into the page below the wire. The force is given by the right-hand rule. It is important to remember to reverse the direction when the particle is negative. Therefore, the force on A is downward, the force on B is to the left, the force on C is upward, and the force on D is to the left. The blue arrows added to the figure show the directions of the forces. The correct answer is **(c)**.

10. In which of the wires does the current induced by the changing flux flow clockwise?



(a) N magnetic pole moving toward coil from above the page

(b) N magnetic pole moving toward the coil in the plane of the page

(c) Pulling the coil to the right out of a magnetic field that points out of the page

(d) Shrinking a coil in a magnetic field pointing into the page

Lenz's Law says that the current will flow to counteract the change in magnetic flux. In case (a), the magnetic field is increasing into the page, which would be counteracted by a counterclockwise current. In case (b), there is no magnetic flux, because the field is perpendicular to the loop. In case (c), the field out of the page is decreasing, which would be counteracted by a counterclockwise current. In case (d), the flux into the page is decreasing, which is counteracted by a field into the page, which would be created by a clockwise current. Therefore, **(d)** is the correct answer.

11. Assume the primary winding on a step-down transformer on a utility pole has a resistance of 10 ohms and an inductance of 0.3 Henry. Estimate the r.m.s. current flowing through the primary winding if the voltage is 2,400 volts, r.m.s.

(a) 240 A (b) 133 A **(c)** 20 A (d) 2.7×10^5 A

If the current were limited only by the resistance, it would be $I = 2{,}400 \text{ V}/10\Omega = 240$ A. However, this is AC current in an inductor, so the reactance must be taken into account. The inductive reactance is $X_L = 2\pi f L$, where $f = 60$ Hz is the frequency of AC current. Therefore, $X_L = 113\Omega$, which is much greater than the DC resistance, so the reactance is primarily what limits the current, giving $I = 2{,}400 \text{ V}/113\Omega = 21$ A. Answer **(c)** is closest.

12. The peak value of the **E** field in an electromagnetic wave is 26.5 mV/m. What is the average rate at which this wave carries power across a unit area?

(a) 1.9×10^{-6} W/m^2 **(b)** 9.3×10^{-7} W/m^2

(c) 1.3×10^{-6} W/m^2 (d) 4.6×10^{-7} W/m^2

In terms of the peak electric field E, the average rate of power flow per unit area is given by the average value of the Poynting vector,

$$S = \tfrac{1}{2}\varepsilon_0 c E^2 = 0.5\,(8.85 \times 10^{-12}\ \text{C}^2/\text{Nm}^2)\,(3.0 \times 10^8\ \text{m/s})\,(0.0265\ \text{N/C})^2$$
$$= \mathbf{9.3 \times 10^{-7}\ W/m^2}.$$

13. The variable capacitor in the tuner of an AM radio has a capacitance of 2400 pF when the radio is tuned to a station at 550 kHz. What must the capacitance be to tune as station at the other end of the dial, 1550 kHz?

(a) 850 pF (b) 6.7 μF **(c)** 300 pF (d) 19 μF

The resonance condition for the tuner is $LC = 1/(2\pi f)^2$. Comparing two different cases with a fixed inductance L shows that $C_2/C_1 = (f_1/f_2)^2$. Taking $C_1 = 2400$ pF when $f_1 = 550$ kHz gives the capacitance C_2 corresponding to frequency $f_2 = 1550$ kHz to be

$$C_2 = (2400\ \text{pF})\,(550\ \text{kHz}/1550\ \text{kHz})^2 = \mathbf{302\ pF}.$$

14. Which waves will travel most easily around hills and buildings?

(a) AM radio (b) TV VHF signal (c) microwaves (d) X-rays

Longer wavelengths diffract more easily around large objects than short wavelengths. Therefore, **AM radio** will travel most easily around obstacles. The wavelengths of the four choices are ordered from longest wavelength to shortest.

15. A microscope uses an eyepiece with a focal length of 1.5 cm. Using a normal eye with a final image at infinity, the tube length is 17.5 cm and the focal length of the objective lens is 0.65 cm. What is the magnification of the microscope? Select the closest answer.

(a) 1000 x **(b)** 500 x (c) 250 x (d) 100 x

The magnification of a microscope is given by $M = N\, L\, /\, f_o f_e$ in terms of the near point $N = 25$ cm of the normal eye, the length $L = 17.5$ cm of the microscope tube, and the focal lengths $f_o = 0.65$ cm and $f_e = 1.5$ cm of the objective lens and eyepiece. Putting these numbers together gives a magnification of 448 times. Answer **(b)** is closest.

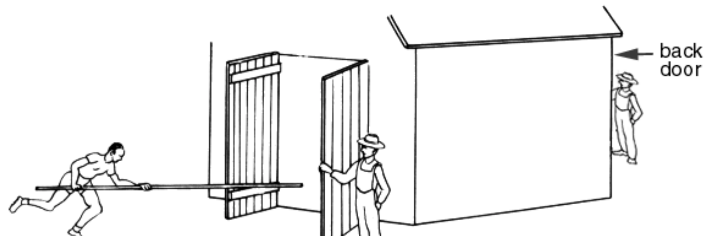
16. A photographer photographs the same subject in the morning and afternoon with different lighting. He finds that the same exposure time he used with an aperture of *f*/5.6 in the morning is obtained with an *f*/22 aperture in the afternoon. By what factor has the intensity of the light increased between morning and afternoon?

(a) 4 x (b) 8 x **(c)** 16 x (d) 24 x

The amount of light striking the film is proportional to the intensity times the aperture area, and the aperture area is inversely proportional to the square of the *f*-stop, so the amount of light striking the film is proportional to the intensity divided by the square of the *f*-stop. Since the amount of light striking the film is held constant while the *f*-stop was increased by a factor of 22/5.6 = 3.9, that means the intensity increased by a factor of $(3.9)^2$ = **15.4**. The closest answer is **(c)**.

17.

A farmer bets a very fast pole-vaulter that if he runs close to the speed of light, he can fit his pole into the barn even though it is longer than the barn.



The pole is longer than the barn, but appears shorter to the farmer.

Consider the following three statements…

1. The farmer and an accomplice simultaneously shut the doors on both ends of the barn when the pole-vaulter is inside, and the farmer claims his bet.
2. The pole-vaulter sees the barn shrink, and sees that he must win, because his pole is even longer than the barn than it was before.
3. The pole-vaulter sees the farmer and his accomplice shut the doors, but he bursts out the one in the back before the one he entered in the front is ever closed.

Which of the three statements could be true relativistically?

(a) 1 (b) 2 (c) 3 (d) 2 and 3 (e) all of them

The farmer sees the length of the pole contracted to be shorter than the barn, so he can close both doors at a time when the entire pole is inside the barn. Statement 1 is then true.

In the pole-vaulter's rest frame, the barn is moving past him very fast, and is Lorentz-contracted so that to him, it appears to be shorter than his pole by an even greater factor than when he was standing still. Therefore, statement 2 is also true.

In relativity, simultaneity depends on one's reference frame. The fact that the pole-vaulter sees his pole as being longer than the barn means that the front and back doors cannot be closed at the same time in his reference frame. When his pole bursts through the back door, the back of the pole is still outside, and the back door is not closed until it comes inside, at a later time. This means that statement 3 is also true.

The fact that the pole appears to fit in the barn for the farmer and not for the pole-vaulter is resolved by the fact that the doors being closed are simultaneous events only for the farmer, not for the pole-vaulter. From the pole-vaulter's point of view, his pole is never completely enclosed in the barn, though it is from the farmer's point of view. **All three statements are true**, relativistically.

18. What spectral series of Hydrogen is the 365 nm line in? Recall that the ionization energy of Hydrogen is 13.6 eV, if that helps.

(a) Lyman series (b) Balmer series (c) Paschen series

A 365 nm (UV) line corresponds to an energy of $E = hc/\lambda$ = (1.24 keV nm)/365 nm = 3.397 eV. The Balmer lines have energies up to a limit of 13.6 eV/2^2 = 3.40 eV, so this could be a transition between n = 2 and one of the closely spaced levels at n approaching infinity. There are no energies this small in the Lyman series, where the smallest energy difference is 13.6 eV – 3.40 eV = 10.2 eV, and none so large in the Paschen series, where the upper limit is 13.6 eV/3^2 = 1.5 eV. The answer is therefore **(b)**.

19. Which of the following electron configurations is possible for an atom?

(a) $1s^2\ 2s^2\ 2p^6\ 2d^4\ 3s^2\ 3p^4$ **(b)** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^7$

(c) $1s^2\ 2s^2\ 2p^7\ 3s^1$ (d) $1s^2\ 1p^2\ 2s^2\ 2p^4$

Case (a) can be ruled out because there is no 2d state. Case (c) can be ruled out because you can't put more than 6 electrons in the 2p orbitals. Case (d) can be ruled out because there is no 1p state. This leaves **(b)**, which is allowed.

20. One of the carriers of the weak nuclear force is the Z boson, which is similar to a massive photon. It has a mass of 91.187 GeV/c^2 and a width of 2.49 GeV/c^2, where the width is the variation among mass measurements obtained for many measurements. Assuming this variation is due to the Heisenberg uncertainty principle, estimate the lifetime of the Z boson. Select the closest estimate. Recall that 1 GeV = 10^9 eV.

(a) 2.6 x 10^{-25} s (b) 1.7 x 10^{-25} s (c) 7.2 x 10^{-27} s (d) 2.8 x 10^{-16} s

There is an uncertainty of 2.49 GeV in the rest energy of the Z boson, which may be attributed to the Heisenberg uncertainty principle and the limitation placed on the time that the mass can be measured because the particle is unstable. The lifetime τ can be estimated from the energy-time uncertainty principle $\Delta E\ \tau > h/2\pi$ by setting

$$\tau = h\ /\ (2\pi \text{ x } 2.49 \text{ GeV}) = hc\ /\ (2\pi \text{ x } 2.49 \text{ GeV})\ c$$
$$= (1.24 \text{ keV x } 10^{-9} \text{ m})/[2\pi \text{ x } (2.49 \text{ x } 10^{6} \text{ keV}) \text{ x } (3\text{x } 10^{8} \text{ m/s})] = \mathbf{2.6 \text{ x } 10^{-25} \text{ s}}.$$