

PHYSICS 112 - EXAM 4 (first part of final exam) - FALL 2003

Name _____ Section _____

Use only a right-handed coordinate system ($+x$, $+y$, $+z$ along thumb, forefinger, and middle finger of your right hand when these three fingers are perpendicular to one another). Show your calculations to get full credit. Be sure to include correct units.

1. [6 points total] A two-slit system consists of two slits, each of width $3.00 \mu\text{m}$, whose centers are separated by a distance of $12.0 \mu\text{m}$. Light of wavelength $0.600 \mu\text{m}$ shines on the slits.

(a) [2 points] Determine the numerical value of $\sin \theta$ for the angle corresponding to the first diffraction minimum.

(b) [2 points] Determine the numerical value of $\sin \theta$ for the angle corresponding to the fourth interference maximum.

(c) [2 points] What number interference maximum coincides with the second diffraction minimum?

2. [3 points] In a two-slit system the separation of the slits is three times their width. Make an approximate sketch of the light intensity pattern seen on a screen far past the slits when it is illuminated with monochromatic light. Show at least two diffraction minima on each side of the central maximum, and show which interference maxima appear to be missing.

3. [10 points total] When white light is incident normally (perpendicularly) from air onto a thin film of oil with an index of refraction of 1.200 floating on water ($n = 1.33$), it is found that there is constructive interference at a wavelength of 600 nm (this is the wavelength in air).

(a) [2 points] Determine the phase change, if any, of the reflections at the top and bottom surfaces of the thin film.

At the top: _____ At the bottom: _____

(b) [2 points] What is the wavelength of this same light in the oil film?

(c) [4 points] What is the smallest possible thickness of the film (to have constructive interference for $\lambda = 600$ nm)?

(d) [2 points] What is the longest wavelength (in air) of electromagnetic radiation for which there would be destructive interference for this same thickness of oil? (This is not necessarily visible light.)

4. [4 points] Louis de Broglie in the early 20th century proposed that particles have wave properties and vice versa, and that their linear momentum p and wavelength λ were related by the simple formula $\lambda = h/p$ (where h is Planck's constant).

Use this equation to determine the formula for the linear momentum p of a photon of frequency f in terms of h , c , and f and also in terms of E and c .

In terms of h , c and f : $p =$

In terms of E and c : $p =$

5. [3 points] The three lowest energy levels of the hydrogen atom have energies -1.51 eV, -3.40 eV, and -13.6 eV. If a sample is prepared of hydrogen atoms in the highest of these levels, determine the energies (in eV) of all the possible photons that might be emitted as the atom decays (in any number of steps) to the lowest state.

6. [2 points] All the energy levels of the hydrogen atom can be expressed by the formula

$$E_n = - (13.6 \text{ eV})/n^2 \text{ where } n = 1, 2, 3, \text{ etc.}$$

If a hydrogen atom in its lowest state ($n = 1$) absorbs a photon, but the atom is not ionized (that is, the electron remains bound to the hydrogen nucleus), what is the maximum energy (in eV) the absorbed photon could have?

7. [9 points] A radioactive isotope of radium (whose symbol is Ra and whose atomic number is 88) decays by alpha-decay into an isotope of radon (symbol: Rn) with an atomic mass number of 222.

Determine the atomic mass (or weight) number of the original radium isotope:

_____.

This radium isotope has _____ electrons and its nucleus has _____ protons and _____ neutrons.

Write down the equation for this radioactive decay, including the proper designations for the radium and radon isotopes:

The total number of quarks in the nucleus of the radon isotope is _____.

8. [3 points] Consider these two isotopes of different elements: $^{107}_{46}\text{Pd}$ (palladium) and $^{107}_{47}\text{Ag}$ (silver). Describe the differences, if any, between the number of neutrons, the number of protons, and the number of quarks in the nuclei of these two isotopes.

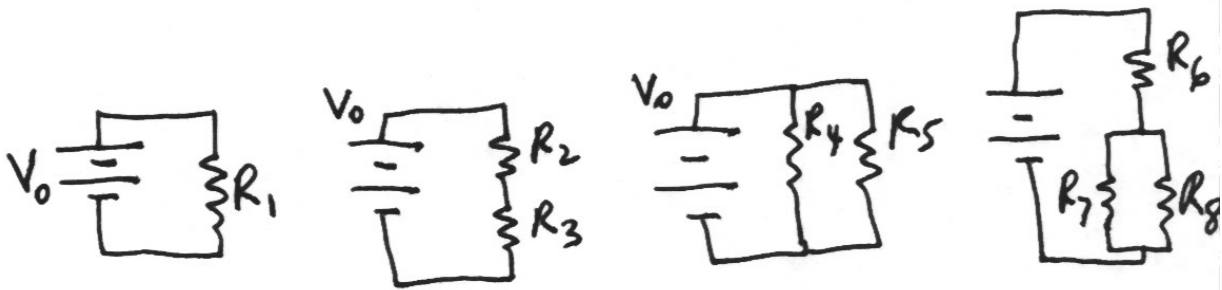
PHYSICS 112 - FINAL EXAM (second, comprehensive part) - FALL 2003

$$\cos^2 0^\circ = 1 \quad \cos^2 30^\circ = 0.75 \quad \cos^2 45^\circ = 0.50 \quad \cos^2 60^\circ = 0.25 \quad \cos^2 90^\circ = 0.$$

1. (a) [2 points]. Determine the electric potential at a point 3.0 m away from a charge of $+2.0 \mu\text{C}$:

(b) [2 points] If this charge is held fixed and another $+3.0 \mu\text{C}$ charge is placed at that point and then released at rest, will the second charge remain at rest or will it move? If it moves, describe the direction in which it moves?

(c) [2 points] After a long time, what will be the kinetic energy (in J) of the second charge?



2. (7 points) Shown above are four circuits, each with the same battery with the same potential difference V_0 . The resistors are individually labeled, but each has the same resistance R ($R_1 = R_2 = \dots = R_8 = R$). Suppose that in the circuit at the left, the current through R is 9 A. Determine the current in each of the other resistors.

$$I_2 = \underline{\hspace{2cm}} \quad I_3 = \underline{\hspace{2cm}} \quad I_4 = \underline{\hspace{2cm}} \quad I_5 = \underline{\hspace{2cm}}$$

$$I_6 = \underline{\hspace{2cm}} \quad I_7 = \underline{\hspace{2cm}} \quad I_8 = \underline{\hspace{2cm}}$$

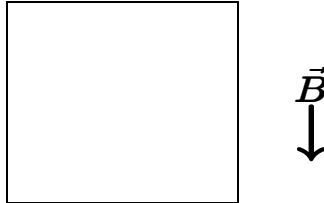
3. A 60-V battery is connected in series to a 6-ohm resistor and a 4-ohm resistor.

(a) [2 points] What is the current through the 6-ohm resistor?

(b) [2 points] What is the power dissipated by the 4-ohm resistor?

(c) [2 points] What is the total power delivered by the battery?

4. [9 points total] A square current loop whose sides are each 0.20 m long is placed in a uniform external magnetic field \vec{B} of magnitude 2.0 T, as shown in the diagram. The loop has a current of 3.0 A in the clockwise direction.



(a) [2 points] Determine the direction of the magnetic force on each side of the loop (top, right, bottom, and left sides).

Left side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow
Top side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow
Right side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow
Bottom side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow

(b) [2 points] Determine the magnitude of the magnetic force on the bottom side.

(c) [2 points] Describe in words how this loop will tend to rotate.

(d) [3 points] When the loop is positioned so there is no net torque acting on it, what is the magnetic flux through it due to the external magnetic field?

5. [8 points] An object 1.5 mm high is located on the principal axis of a convergent lens with a focal length of 10.0 cm, at a distance of 5.0 cm from the lens. Use the lens equation to determine (with the correct signs):

the image distance: _____

the magnification: _____

the height of the image: _____

the nature of the image (real or virtual): _____

the orientation of the image (erect or inverted): _____

(No diagram is necessary, but you are welcome to use one to check your answers.)

6. [4 points] Randomly polarized light is passed through two polarizers. 50% of the light is found to pass through the first polarizer, and 37.5% (of the original intensity) passes through the second polarizer. Determine a possible pair of angles (relative to the $+x$ axis) for each polarizer that is consistent with these results. (There is more than one correct answer, but also LOTS of wrong ones.)

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Name _____ Section _____

Use only a right-handed coordinate system (+ x , + y , + z along thumb, forefinger, and middle finger of your right hand when these three fingers are perpendicular to one another). Show your calculations to get full credit. Be sure to include correct units.

1. [6 points total] A two-slit system consists of two slits, each of width $3.00 \mu\text{m}$, whose centers are separated by a distance of $12.0 \mu\text{m}$. Light of wavelength $0.600 \mu\text{m}$ shines on the slits.

(a) [2 points] Determine the numerical value of $\sin \theta$ for the angle corresponding to the first diffraction minimum.

$$a \sin \theta = m\lambda = 1 \cdot \lambda \text{ so } \sin \theta = \lambda/a = (0.600 \mu\text{m})/(3.00 \mu\text{m}) = 0.200$$

(b) [2 points] Determine the numerical value of $\sin \theta$ for the angle corresponding to the fourth interference maximum.

$$d \sin \theta = m\lambda \Rightarrow \sin \theta = 4\lambda/d = 4(0.600 \mu\text{m})/(12.00 \mu\text{m}) = 0.200$$

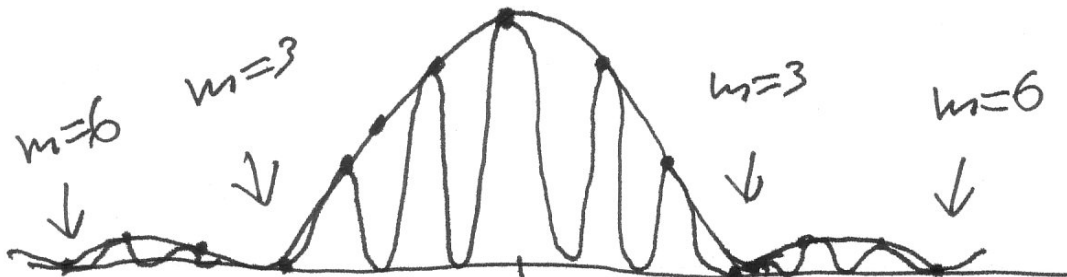
(c) [2 points] What number interference maximum coincides with the second diffraction minimum?

$$a \sin \theta = 2\lambda \text{ and } d \sin \theta = m\lambda \text{ so } a/d = 2/m \text{ and}$$

$$m = 2d/a = 2(12.0 \mu\text{m})/(3.00 \mu\text{m}) = 2 \cdot 4 = 8.$$

The eighth interference maximum corresponds with the second diffraction minimum.

2. [3 points] In a two-slit system the separation of the slits is three times their width. Make an approximate sketch of the light intensity pattern seen on a screen far past the slits when it is illuminated with monochromatic light. Show at least two diffraction minima on each side of the central maximum, and show which interference maxima appear to be missing.



3. [10 points total] When white light is incident normally (perpendicularly) from air onto a thin film of oil with an index of refraction of 1.200 floating on water ($n = 1.33$), it is found that there is constructive interference at a wavelength of 600 nm (this is the wavelength in air).

(a) [2 points] Determine the phase change, if any, of the reflections at the top and bottom surfaces of the thin film.

At the top: _____ At the bottom: _____

Both phase changes are 180° because both are reflections off a fluid with a higher index of refraction.

(b) [2 points] What is the wavelength of this same light in the oil film?

$$\lambda_{\text{film}} = \lambda_{\text{air}}/n_{\text{film}} = (600 \text{ nm})/(1.20) = 500 \text{ nm}.$$

(c) [4 points] What is the smallest possible thickness of the film (to have constructive interference for $\lambda = 600 \text{ nm}$)?

The reflections have provided no difference in phase, so the condition on the thickness for constructive interference is

$$2t = m\lambda \text{ for } m = 1 \text{ or } 2t = \lambda_{\text{film}} \text{ and } t = \lambda_{\text{film}}/2 = (500 \text{ nm})/2 = 250 \text{ nm}.$$

(d) [2 points] What is the longest wavelength (in air) of electromagnetic radiation for which there would be destructive interference for this same thickness of oil? (This is not necessarily visible light.)

Now the condition is, instead, $2t = (m + \frac{1}{2})\lambda_{\text{film}}$ for $m = 0$, or $2t = \frac{1}{2}\lambda_{\text{film}}$, so

$$\lambda_{\text{film}} = 4t = 4(250 \text{ nm}) = 1000 \text{ nm} \text{ and}$$

$$\lambda_{\text{air}} = n_{\text{film}}\lambda_{\text{film}} = (1.20)(1000 \text{ nm}) = 1200 \text{ nm}.$$

4. [4 points] Louis de Broglie in the early 20th century proposed that particles have wave properties and vice versa, and that their linear momentum p and wavelength λ were related by the simple formula $\lambda = h/p$ (where h is Planck's constant).

Use this equation to determine the formula for the linear momentum p of a photon of frequency f in terms of h , c , and f and also in terms of E and c .

In terms of h , c and f : $p = h/\lambda = h/(c/f) = hf/c$

In terms of E and c : $p = hf/c = E/c$

5. [3 points] The three lowest energy levels of the hydrogen atom have energies -1.51 eV, -3.40 eV, and -13.6 eV. If a sample is prepared of hydrogen atoms in the highest of these levels, determine the energies (in eV) of all the possible photons that might be emitted as the atom decays (in any number of steps) to the lowest state.

These are levels 3, 2, and 1, respectively. The energies of possible emitted photons are just the energy differences for transitions from a higher level to a lower level; there are three:

$$n = 3 \rightarrow n = 2: -1.51 \text{ eV} - (-3.40 \text{ eV}) = 1.89 \text{ eV}.$$

$$n = 3 \rightarrow n = 1: -1.51 \text{ eV} - (-13.6 \text{ eV}) = 12.1 \text{ eV}.$$

$$n = 2 \rightarrow n = 1: -3.40 \text{ eV} - (-13.60 \text{ eV}) = 10.2 \text{ eV}.$$

6. [2 points] All the energy levels of the hydrogen atom can be expressed by the formula

$$E_n = -(13.6 \text{ eV})/n^2 \text{ where } n = 1, 2, 3, \text{ etc.}$$

If a hydrogen atom in its lowest state ($n = 1$) absorbs a photon, but the atom is not ionized (that is, the electron remains bound to the hydrogen nucleus), what is the maximum energy (in eV) the absorbed photon could have?

The maximum energy of the absorbed photon would be the energy that changes the state from the lowest ($n = 1$) to the highest, effectively $n = \infty$. The absorbed energy is then

$$0 \text{ eV (energy for very large } n) - (-13.6 \text{ eV}) = 13.6 \text{ eV}.$$

That's the maximum energy the absorbed photon can have and yet not ionize the atom.

7. [9 points] A radioactive isotope of radium (whose symbol is Ra and whose atomic number is 88) decays by alpha-decay into an isotope of radon (symbol: Rn) with an atomic mass number of 222.

Determine the atomic mass (or weight) number of the original radium isotope:

It must have been the sum of 4 (from the alpha-particle) and 222, or 226.

This radium isotope has 88 electrons and its nucleus has 88 protons and

$226 - 88 = 138$ neutrons.

Write down the equation for this radioactive decay, including the proper designations for the radium and radon isotopes:



The total number of quarks in the nucleus of the radon isotope is $3 \times 222 = 666$.

8. [3 points] Consider these two isotopes of different elements: $^{107}_{46}\text{Pd}$ (palladium) and $^{107}_{47}\text{Ag}$ (silver). Describe the differences, if any, between the number of neutrons, the number of protons, and the number of quarks in the nuclei of these two isotopes.

Neutrons: $107 - 46 = 61$ in the palladium and $107 - 47 = 60$ in the silver, so

the palladium has one more neutron in its nucleus.

Protons: 46 in the palladium and 47 in the silver, so the silver has one more proton in its nucleus.

Quarks: Both have $107 \times 3 = 321$ quarks in their nuclei.

PHYSICS 112 - FINAL EXAM (second, comprehensive part) - FALL 2003

$$\cos^2 0^\circ = 1 \quad \cos^2 30^\circ = 0.75 \quad \cos^2 45^\circ = 0.50 \quad \cos^2 60^\circ = 0.25 \quad \cos^2 90^\circ = 0.$$

1. (a) [2 points]. Determine the electric potential at a point 3.0 m away from a charge of $+2.0 \mu\text{C}$:

$$V = kQ/r = (9 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(2.0 \times 10^{-6} \text{ C})/(3.0 \text{ m}) = 6 \times 10^3 \text{ V}$$

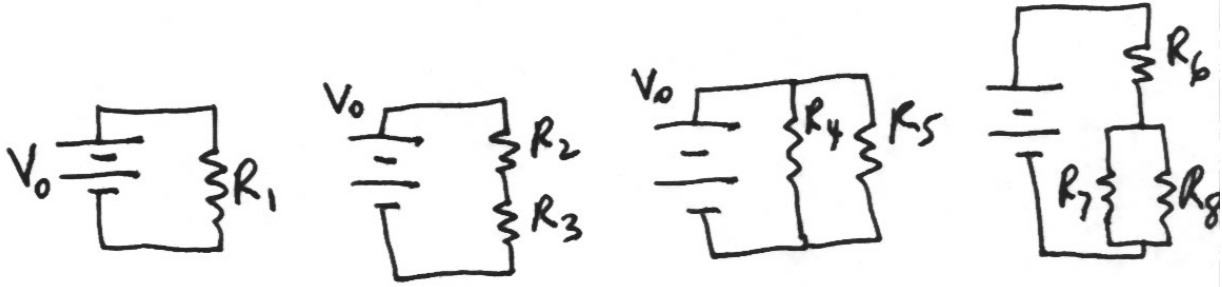
(b) [2 points] If this charge is held fixed and another $+3.0 \mu\text{C}$ charge is placed at that point and then released at rest, will the second charge remain at rest or will it move? If it moves, describe the direction in which it moves?

The second charge, having the same sign as the fixed charge, will move directly away from it.

(c) [2 points] After a long time, what will be the kinetic energy (in J) of the second charge?

After a long time, when the second charge is so far away that its potential energy is zero, its kinetic energy must be equal to the initial electric potential energy of the pair of charges:

$$\begin{aligned} kq_1q_2/r &= (9 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(+2.0 \times 10^{-6} \text{ C})(+3.0 \times 10^{-6} \text{ C})/(3.0 \text{ m}) \\ &= 18 \times 10^{-3} \text{ J or } 0.018 \text{ J.} \end{aligned}$$



2. (7 points) Shown above are four circuits, each with the same battery with the same potential difference V_0 . The resistors are individually labeled, but each has the same resistance R ($R_1 = R_2 = \dots = R_8 = R$). Suppose that in the circuit at the left, the current through R is 9 A. Determine the current in each of the other resistors.

$$I_2 = \underline{\hspace{2cm}} \quad I_3 = \underline{\hspace{2cm}} \quad I_4 = \underline{\hspace{2cm}} \quad I_5 = \underline{\hspace{2cm}}$$

$$I_6 = \underline{\hspace{2cm}} \quad I_7 = \underline{\hspace{2cm}} \quad I_8 = \underline{\hspace{2cm}}$$

I_2 and I_3 must be half of 9 A, or 4.5 A.

I_4 and I_5 must be equal to I_1 , since the resistors have the full potential difference V_0 of the battery across them.

$$\text{In the last circuit, the equivalent resistance is } R + \frac{1}{\frac{1}{R} + \frac{1}{R}} = R + \frac{1}{2}R = \frac{3}{2}R$$

so the current through R_6 is $2/3$ of the original current in the first circuit, or 6 A. This divides equally between R_7 and R_8 .

3. A 60-V battery is connected in series to a 6-ohm resistor and a 4-ohm resistor.

(a) [2 points] What is the current through the 6-ohm resistor?

The equivalent resistance $R_{eq} = 6 \Omega + 4 \Omega = 10 \Omega$ so the current in the circuit is

$$I = (60 \text{ V}) / (10 \Omega) = 6 \text{ A. This is the current through the 6- and the 4-ohm resistors.}$$

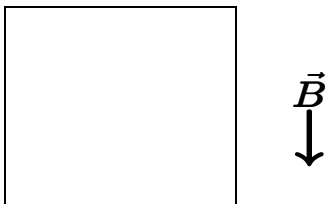
(b) [2 points] What is the power dissipated by the 4-ohm resistor?

$$\text{This is } P = I^2 R = (6 \text{ A})^2 (4 \Omega) = 144 \text{ W.}$$

(c) [2 points] What is the total power delivered by the battery?

$$\text{The total power delivered by the battery is } I \Delta V = (6 \text{ A})(60 \text{ V}) = 360 \text{ W.}$$

4. [9 points total] A square current loop whose sides are each 0.20 m long is placed in a uniform external magnetic field \vec{B} of magnitude 2.0 T, as shown in the diagram. The loop has a current of 3.0 A in the clockwise direction.



(a) [2 points] Determine the direction of the magnetic force on each side of the loop (top, right, bottom, and left sides).

Left side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow
Top side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow
Right side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow
Bottom side:	0	\odot	\otimes	\uparrow	\downarrow	\leftarrow	\rightarrow

Answers: down (\otimes) on the top side, 0 on the right and left sides, up (\odot) on the bottom side.

(b) [2 points] Determine the magnitude of the magnetic force on the bottom side.

$$F = BIL \sin \theta = (2.0 \text{ T})(3.0 \text{ A})(0.20 \text{ m}) \sin 90^\circ = 0.12 \text{ N}.$$

(c) [2 points] Describe in words how this loop will tend to rotate.

It will tend to rotate so the top edge goes down and the bottom edge goes up, which would be counterclockwise as viewed from the left side of the page.

(d) [3 points] When the loop is positioned so there is no net torque acting on it, what is the magnetic flux through it due to the external magnetic field?

$$\text{It will be } \Phi = BA \cos \theta = (2.0 \text{ T})(0.20 \text{ m})^2 (\cos 0^\circ) = 0.080 \text{ T} \cdot \text{m}^2.$$

5. [8 points] An object 1.5 mm high is located on the principal axis of a convergent lens with a focal length of 10.0 cm, at a distance of 5.0 cm from the lens. Use the lens equation to determine (with the correct signs):

the image distance: _____

the magnification: _____

the height of the image: _____

the nature of the image (real or virtual): _____

the orientation of the image (erect or inverted): _____

(No diagram is necessary, but you are welcome to use one to check your answers.)

$$1/i = 1/f - 1/o = 1/10 \text{ cm} - 1/5.0 \text{ cm} = 1/10 \text{ cm} - 2/10 \text{ cm} = -1/10 \text{ cm}$$

$$\text{so } i = -10 \text{ cm.}$$

$$m = -i/o = -(-10 \text{ cm})/5 \text{ cm} = +2.$$

$$\text{The height of the image is } m(1.5 \text{ mm}) = 2(1.5 \text{ mm}) = 3.0 \text{ mm.}$$

The image is virtual and erect.

6. [4 points] Randomly polarized light is passed through two polarizers. 50% of the light is found to pass through the first polarizer, and 37.5% (of the original intensity) passes through the second polarizer. Determine a possible pair of angles (relative to the +x axis) for each polarizer that is consistent with these results. (There is more than one correct answer, but also LOTS of wrong ones.)

The first polarizer could be anything, of course. The angle between the first and second must be such that the difference in angle $\Delta\theta$ gives $\cos^2(\Delta\theta) = 0.75$. This suggests $\Delta\theta = 30^\circ$.

The angles could be 0° and 30° or 10° and 40° , for example.
