General Physics: Final Exam

13 May 2013

Name: SOLUTION **Total:** /150

Instructions

- There are 16 questions on 11 pages.
- Show your reasoning and calculations and always justify your answers.

Physical constants and useful formulae

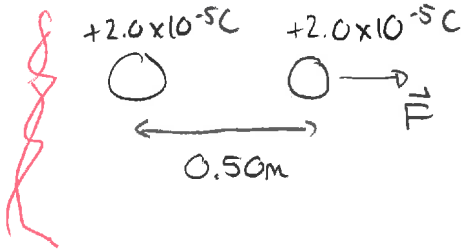
Coulomb's constant:	$k = 9.0 \times 10^9\,\mathrm{Nm^2/C^2}$
Electron charge:	$q_{\mathrm{electron}} = -1.60 \times 10^{-19}\,\mathrm{C}$
Electron charge magnitude:	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
Electron mass:	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
Proton charge	$q_{\mathrm{proton}} = +1.60 \times 10^{-19}\,\mathrm{C}$
Proton mass:	$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
Neutron mass:	$m_n = 1.67 \times 10^{-27}\,\mathrm{kg}$
Permitivity of free space:	$\epsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/Nm^2}$
Permeability of free space:	$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{Tm/A}$
Speed of light:	$c = 3.00 \times 10^8\,\mathrm{m/s}$
Planck's constant:	$h = 6.63 \times 10^{-34}\,\mathrm{Js} = 4.14 \times 10^{-15}\,\mathrm{eV\ s}$
eV conversion:	$1\,\mathrm{eV} = 1.60 \times 10^{-19}\,\mathrm{J}$

77
74

Question 1

Two identical small conducting spheres on perfectly insulating stands are initially separated. Initially one holds a total charge 4.0×10^{-5} C, the other is uncharged. The spheres are brought into contact and held this way until the charge redistributes itself into a settled state. They are then separated and held a distance of 0.50 m apart. Determine the charge on each individual sphere and the force, including direction, exerted by one sphere on the other at the end of this process.

+2 The charge will be shared evenly. So each will have charge 2.0×10^{-5}C



+2 $F = k \frac{|q_1||q_2|}{r^2}$

$= 9.0 \times 10^9 \, N m^2/C^2 \; \frac{2.0 \times 10^{-5} C \times 2.0 \times 10^{-5} C}{(0.50 m)^2}$

$F = 14.4$ N

+1 They repel

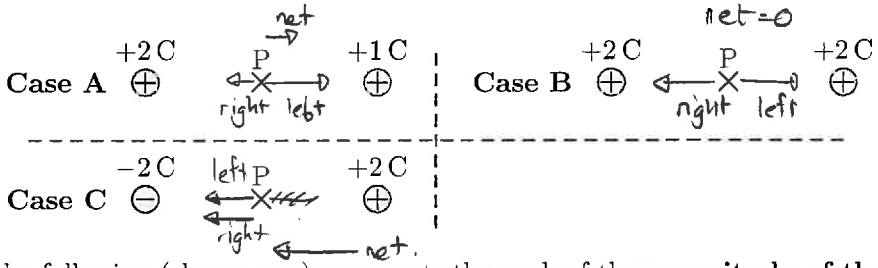
/5

78
89

Question 2

Three isolated pairs of charges are separated by the same distance.

Two fields contribute at each P



Which of the following (choose one) represents the rank of the **magnitude of the electric field at P**?

a) Case B > Case A > Case C
b) Case C > Case A > Case B
c) Case B = Case C > Case A
d) Case A > Case B > Case C

/5

60
71

most lost on part b)

Question 3

Two large parallel plates are separated by 0.20 m and are charged giving rise to illustrated electric potentials. The electric field between the plates is uniform. An electron is initially held at rest on the left plate (that with potential −100 V).

a) The electron is released and eventually hits the plate on the right (that with potential 300 V). Determine the speed of the electron at the instant before it hits the plate on the right.

+2

Energy is conserved $\Delta K + \Delta U_{elec} = 0$. But $\Delta U_{elec} = q\Delta V$ +2

$\Rightarrow \Delta K = -q\Delta V \Rightarrow K_f - K_i = -q\Delta V$

+1 [$K_i = 0$ since initially at rest and $K_f = \frac{1}{2}mv_f^2$] +1

+4

$\Rightarrow \frac{1}{2}mv_f^2 = -q\Delta V \Rightarrow v_f^2 = \frac{-2q\Delta V}{m}$

$= -\frac{2(-1.6\times10^{-19}\,C)(300\,V-(-100\,V))}{9.11\times10^{-31}\,kg}$

$= 1.4\times10^{14}\ m^2/s^2$

$\Rightarrow v_f = \sqrt{1.4\times10^{14}\ m^2/s^2} = 1.2\times10^7\ m/s$

+5

b) Another charged particle, called Zog, is held at rest midway between the plates and released. Which of the following (choose one) is true regarding the direction of the electric field produced *by the plates* at the midpoint?

Field same regardless of probe charge. Field points down potential hill ←

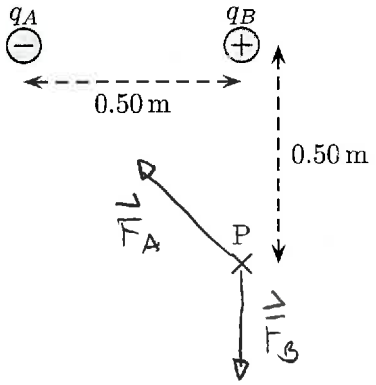
i) → if Zog is negative, ← if Zog is positive.
ii) ← if Zog is negative, → if Zog is positive.
iii) ← regardless of Zog's charge.
iv) → regardless of Zog's charge.
v) The electric field at the midpoint is zero.

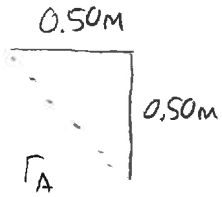
/15

66
66

Question 4

Two fixed charges are situated as illustrated. Their charges are $q_A = -6.0\times10^{-9}$ C and $q_B = 3.0\times10^{-9}$ C. Determine the magnitude of the force exerted on another particle with charge +0.25 C placed at the point labeled P.

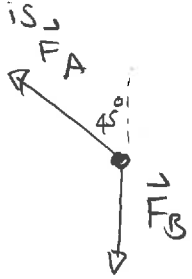




$r_A = \sqrt{0.50^2+0.50^2}$

$= 0.71\,m$

+3 The FBD is



+1 $\vec{F}_{net} = \vec{F}_A + \vec{F}_B$ means adding vectors via components

+3 First magnitudes: $F_A = k\dfrac{|q_A||q_{at\,P}|}{r_A^2} = \dfrac{9.0\times10^9\,Nm^2/C^2 \times 6\times10^{-9}C \times 0.25C}{(0.71m)^2}$

$= 27\,N$

+3 $F_B = k\dfrac{|q_B||q_{at\,P}|}{r_B^2} = \dfrac{9.0\times10^9\,\frac{Nm^2}{C^2} \times 3.0\times10^{-9}C \times 0.25C}{(0.50m)^2}$

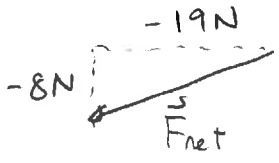
$= 27\,N$

Components

+4

	x	y
$\vec{F}_A$	$-F_A\cos45° = -19\,N$	$F_A\sin45° = 19\,N$
$\vec{F}_B$	0	$-27\,N$
$\vec{F}_{net}$	$-19\,N$	$-8\,N$

+2



$F_{net} = \sqrt{19\,N^2 + 8N^2}$

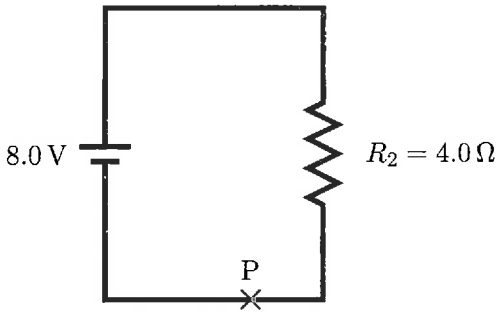
$= 21\,N$ +2

/18

68
74
Part b) tricky

Question 5

A resistor is connected to a battery as illustrated.



a) Determine the current that flows through the circuit and the time taken for a total charge of 10 C to pass point P as illustrated.

+3

$\Delta V = IR$

$\Rightarrow I = \frac{\Delta V}{R} = \frac{8.0\,V}{4.0\,\Omega} = 2.0\,A$

+3

$I = \frac{\Delta Q}{\Delta t} \Rightarrow$ ~~$\Delta Q = I\Delta t \Rightarrow \Delta C$~~

$\Rightarrow \Delta t = \frac{\Delta Q}{I} = \frac{10\,C}{2.0\,A} = 5.0\,s$

+4

b) Which of the following (choose one) is true regarding the total energy supplied by the battery to move a total charge Q through the resistor?

i) The total energy is Q.
ii) The total energy equals the current flowing through the resistor.
iii) The total energy equals the voltage across the resistor.
iv) None of the above.

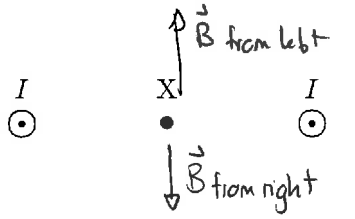
$\Delta U = Q\Delta V$
$= I\Delta t\Delta V$
depends on I and ΔV

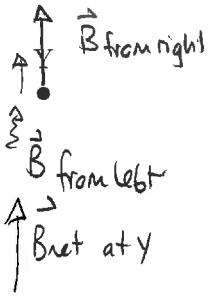
/10

Question 6

86
89

Two very long wires point directly out of the page and carry identical currents, pointing out of the page. Point X is midway between the wires and Y the same distance to the right of the rightmost wire . Which of the following (choose one) is true regarding the magnitudes of the net magnetic fields at points X and Y?





a) $B_X = B_Y = 0$ b) $B_X = B_Y \neq 0$ c) $B_X > B_Y$ d) $B_X < B_Y$

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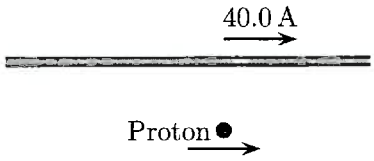
67
72
directions!

Question 7



An infinitely long wire carries currents a current of 40 A. At the instant illustrated below, a proton is at a distance of 1.0×10^{-2} m from the wire and travels with speed 4.0×10^{5} m/s parallel to the wire.

+7 a) Determine the magnetic field (magnitude and direction) produced by the current at the location of the proton.

4 $B = \dfrac{\mu_0 I}{2\pi r} = \dfrac{4\pi \times 10^{-7}\ \text{Tm/A} \times 40\ \text{A}}{2\pi \times 1.0 \times 10^{-2}\ \text{m}} = 8.0 \times 10^{-4}\ \text{T}$

3 Direction by r.h. rule = into page

+7 b) Determine the force (magnitude and direction) exerted by the current on the proton.

4 $\vec{F} = |q| v B \sin\theta$

$= 1.6 \times 10^{-19}\ \text{C} \times 4.0 \times 10^{5}\ \text{m/s} \times 8.0 \times 10^{-4}\ \text{T} \sin 90°$

$= 5.1 \times 10^{-17}\ \text{N}$

$\vec{B}$ into ⊗, $\vec{v}$ →, $\vec{F}$ ↑ by r.h. rule

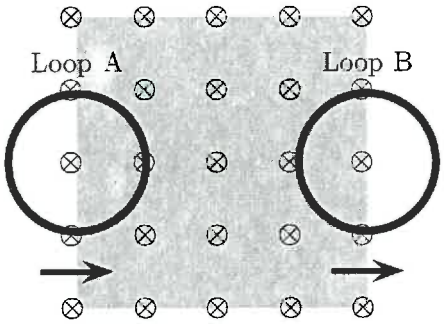
3

/14

43
58

Question 8

There is a uniform constant magnetic field throughout the shaded region. Two loops identical loops are dragged at the at the same rate to the right. Which of the following (choose one) is true regarding the currents in the loops at the indicated moment?



a) $I_A = I_B = 0$.
b) I_A is clockwise, I_B is clockwise.
c) I_A is clockwise, I_B is counterclockwise.
d) I_A is counterclockwise, I_B is clockwise.
e) I_A is counterclockwise, I_B is counterclockwise.

~~Flux in for B~~

Flux in for both. ~~left~~ Right side view

/5

$\vec{B}_{ind}$ ← earlier | Flux increases for A | $\vec{B}_{ext}$ → later

Flux decreases for B

A ⇒ current c.c.w

⇒ current opposite to A

91
97

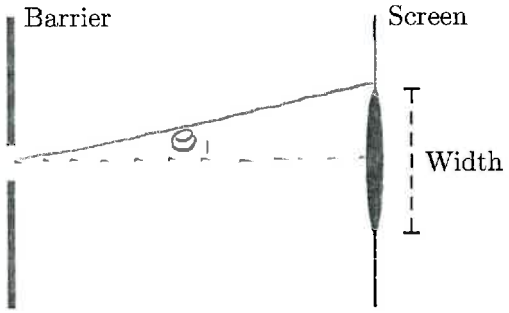
Question 9

A light source illuminates a single slit and produces the illustrated central bright fringe on a screen. This light source is replaced by one with a larger wavelength. Which of the following (choose one) is true regarding the central bright fringe?

a) Width stays same.

b) Width increases.

c) Width decreases.



$a \sin\theta_p = p\lambda$

for first dark $p=1$ $\quad a\sin\theta_1 = \lambda$

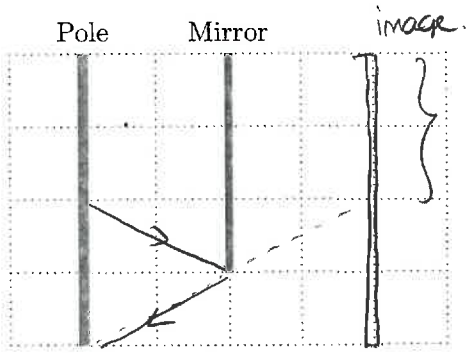
λ up $\Rightarrow$ θ_1 up.

/5

63
79
image length

Question 10

A pole of height 4 m is placed to 2 m to the right of a mirror. The height of the mirror is 3 m and the top of the mirror is level with the pole.



a) Draw the image of the pole produced by the mirror as accurately as possible on the diagram. Determine the height of the image.

+6

By diagram image $\rightarrow$ 4m

distance 4
height 2

b) An ant at the base of the pole looks into the mirror. What length of the image is the ant able to see? Explain your answer.

+4

Look at diagram. Ant sees half of image $\rightarrow$ 2m.

/10

96

Question 11

An object of height 1.0 cm is placed 3.0 cm to the left of a convex lens whose focal length is 2.0 cm.

a) Determine the location of the image produced by the lens *using equations.*

+1 → $f = 2.0\,cm$

+1 → $s = 3.0\,cm$

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

$$\frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{2} - \frac{1}{3}$$

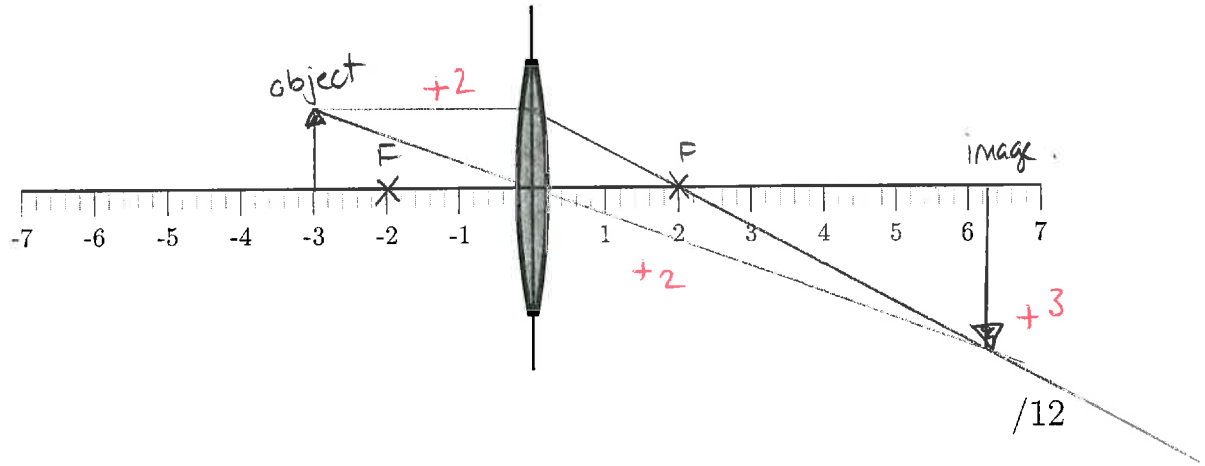
$$= \frac{3-2}{6} = \frac{1}{6}$$

$$\Rightarrow s' = 6\,cm$$

+3

+5

b) Sketch the situation, indicating the object and the image, as accurately as possible using the diagram below.



+7

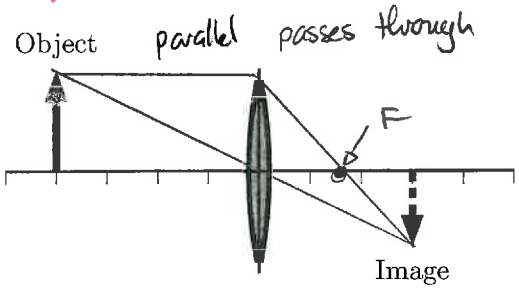
/12

make obj lower

98

Question 12

A thin convex lens is used to produce a real image of an object as illustrated. Which of the following (choose one) is true?



above +4

a) The focal point of the lens is at the location of the image.

b) The focal point of the lens is between the image and the lens.

c) The focal point is right of the image.

Explain your answer (diagrams can be a legitimate part of the explanation).

Look at rays traced. The parallel ray strikes the lens plane an travels to the image. It must pass through focal pt. on optical axis

/8

Question 13

56

Many boxes each have length 4.0×10^{-10} m. One electron is placed in each box. Which of the following is true regarding the light emitted by these electrons?

above +4

a) The emission spectrum consists of exactly one wavelength.

b) The emission spectrum consists of many wavelengths and these have discrete values.

c) The emission spectrum consists of many wavelengths and these have a continuous range of values.

Explain your answer.

Energy quantized $E_n = \frac{h^2}{8mL^2} n^2$, Since $E_{photon} = |\Delta E_{electron}|$

$n=3$ ——— E_3

$\Rightarrow \frac{hc}{\lambda} = |\Delta E_{electron}|$

$n=2$ ——— E_2

$\lambda = \frac{hc}{|\Delta E_{electron}|}$

/8

$n=1$ ——— E_1

only some discrete possibilities

86
93

Question 14

A quantum system has the three illustrated energy levels. Determine *all* the wavelengths of the electromagnetic radiation is the system's emission spectrum.

$E_{photon} = \frac{hc}{\lambda}$

$E_{photon} = |\Delta E_{system}|$

$\Rightarrow \frac{hc}{\lambda} = |\Delta E_{system}| \Rightarrow \lambda = \frac{hc}{|\Delta E_{system}|}$

$= \frac{4.14\times10^{-15}\ eV\cdot s \times 3.0\times10^{8}\ m/s}{|\Delta E_{system}|} = \frac{1.242\times10^{-6}\ m\cdot eV}{(\Delta E_{system})}$

i) $7 \to 3eV$ $\Delta E_{system} = 4.0eV$ $\lambda = \frac{1.242\times10^{-6}\ eV\cdot m}{4eV} = 3.11\times10^{-7}\ m$

ii) $7 \to 1eV$ $\Delta E_{system} = 6.0eV$ $\lambda = \frac{1.242\times10^{-6}\ eV\cdot m}{6eV} = 2.07\times10^{-7}\ m$

iii) $3eV \to 1eV$ $\Delta E_{system} = 2.0eV$ $\lambda = \frac{1.242\times10^{-6}\ eV\cdot m}{2.0eV} = 6.21\times10^{-7}\ m$

/15

54
64

Question 15

A sodium lamp produces light with wavelength 589×10^{-9} m and has power 2.0 W. A laser also has power 2.0 W and lamp produces light with wavelength 650×10^{-9} m. Which of the following (choose one) is true?

$E_{photon} = \frac{hc}{\lambda}$ smaller for mercury

a) Each produces the same number of photons per second.

b) The sodium lamp produces more photons per second.

c) The ~~mercury lamp~~ laser produces more photons per second.

$E_{total} = N E_{photon}$

same — larger mercury — smaller mercury

/5

~~72~~ 72

Question 16

Consider the quantum mechanical model of the hydrogen atom.

a) How many distinct states are there for which $n = 1$? Explain your answer.

3

$l = 0, 1, 2 \ldots, n-1$ $\quad l = 0$ $\quad$ | n | l | m | m_s |

$m = -l, \ldots, l$ $\quad m = 0$ $\quad$ | 1 | 0 | 0 | $\pm 1/2$ |

$m_s = \pm 1/2$ $\quad m_s = +1/2$

2 states

b) How many distinct states are there for which $n = 2$? Explain your answer.

4

n	l	m	m_s
2	0	0	$\pm 1/2$
2	1	-1	$\pm 1/2$
2	1	0	$\pm 1/2$
2	1	+1	$\pm 1/2$

8 states

c) The hydrogen atom undergoes a transition from any of the states for which $n = 2$ to any one of the states for which $n = 1$. Does the wavelength of the emitted light depend on the value of the quantum number l? Explain your answer.

3

~~Now~~ No. $\Delta E_{system} = E_2 - E_1$

$\Downarrow \Downarrow$

E_{photon} $\quad$ only depend on n

$=$

$\frac{hc}{\lambda}$ $\quad$ so λ only depends on n

/10