General Physics II Addendum

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Contents

1 Quantum Physics

§ 1.1 Wavelength and Period of a particle

Theorem: **Wave nature of particles**
A particle with a well defined energy E and momentum p has a period T and wavelength λ such that.

$$E = \frac{h}{T} = hf \qquad \text{AND} \qquad p = \frac{h}{\lambda}$$

or with $\hbar = \frac{h}{2\pi}$ and $\omega = \frac{2\pi}{T}$ and $k = \frac{2\pi}{\lambda}$

$$E = \hbar\omega \qquad \text{AND} \qquad p = \hbar k$$

§ 1.2 Interaction of light and matter

By conservation of energy the follow two theorems are self evident.

Theorem: **Absorption**
If an system has energy levels E_n and if the system absorbs a photon of frequency f then

$$E_{n_{\text{initial}}} + hf = E_{n_{\text{final}}}$$

Theorem: **Emission**
If an system has energy levels E_n and if the system emits a photon of frequency f then

$$E_{n_{\text{initial}}} = E_{n_{\text{final}}} + hf$$

§ 1.3 Wavelength of Massive particle

For light since we know that the speed is always c we can directly relate the wavelength and frequency via $c = \lambda f$. This allows us to write the energy in terms of either the frequency or wavelength.

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

For a massive particle it is not the same. The rate at which the particle wave travel λf is not the speed at which the particle is traveling.

For example if we have a free particle the particle has only kinetic energy and thus

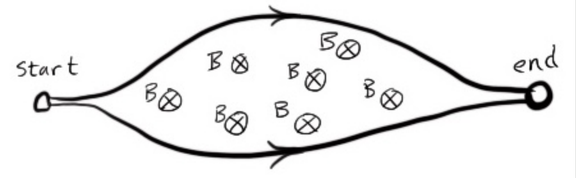
$$E = K = \tfrac{1}{2}mv^2 = \frac{(mv)^2}{2m} = \frac{p^2}{2m} = \frac{(h/\lambda)^2}{2m} = \frac{h^2}{2m\lambda^2}$$

§ 1.4 Phase difference caused by magnetic field

Theorem: **Phase difference caused by magnetic field**
If a quantum particle follows two paths between a starting point and an ending point then there is a phase difference between the two waves associated with the two paths

$$\Delta\phi = 2\pi \frac{q\Phi_B}{h}$$

where q is the charge of the particle and Φ_B is the magnetic flux through the area between the two paths.



▷ Problem 1.1

A stream of electrons are directed toward a double slit. The slits are a distance d apart. There is a magnetic field B that is parallel to the long direction of the slits. A detector is a distance L from the electron source, on the opposite side of the double slit. The detector is placed at the central maximum of the double slit interference pattern, with the magnetic field set to $B = 0$. The magnetic field is slowly increased until the detector is at an interference minimum. What is the magnetic field strength.

2 Review Problems

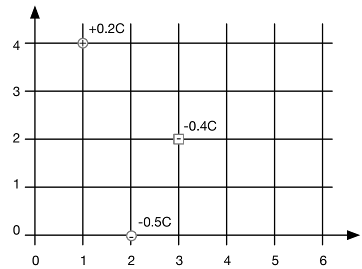
▷ PROBLEM 2.1
What is the RMS speed of a water vapor molecule in the air when the temperature is 300K?

▷ PROBLEM 2.2
Hot water is running through a pipe wrapped in insulation. How much heat is lost per meter per second?

▷ PROBLEM 2.3
Sunlight has an intensity of 1000 W per square meter. How much water can be evaporated per hour?

▷ PROBLEM 2.4
Estimate the temperature of a planet in our solar system, given the radius of the planets orbit relative the radius of the earth's orbit.

▷ PROBLEM 2.5
Compute the force on the -0.4 C charge. The distances in the diagram are in km, use $k = 9000\mathrm{N}\frac{\mathrm{km}^2}{\mathrm{C}^2}$.



▷ PROBLEM 2.6
Two parallel metallic plates are maintained at fixed voltages $V_a = 12$V and $V_b = 18$V, and are separated by a distance of 2mm.
(a) What is the electric field strength between the plates?
(b) Which way does the electric field point?
(c) A particle with a mass of 3.0×10^{-22}kg and charge -3.2×10^{-18}C is placed midway between the plates. To which plate will the particle be attracted? How fast will the particle be going when it strikes that plate?
(d) The capacitance of the parallel plates is 5.0μF, how much charge is on plate a.

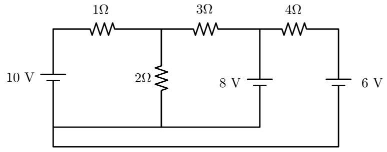
(e) The capacitors are disconnected from the voltage source and at time $t = 0$ a resistor of 2.0kΩ is used to connect the two plates. What is the voltage difference between the plates at a later time t?

▷ PROBLEM 2.7

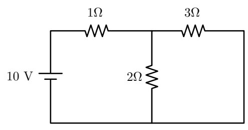
A light bulb is connected to a 12 volt power supply and draws a current of 3.0 amps. What is the power drawn by the light bulb.

▷ PROBLEM 2.8

Find the currents in the four resistors.



▷ PROBLEM 2.9

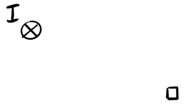


▷ PROBLEM 2.10

A charged particle is moving to the east and enters a region with a uniform magnetic field that is pointed upward. Describe the motion of the particle.

▷ PROBLEM 2.11

There is a current going straight down into the paper at the location indicated. What is the direction of the magnetic field produced by this current at the location of the square?

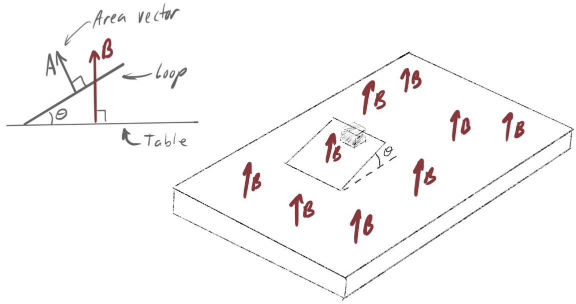


▷ PROBLEM 2.12

You put a magnet on an arrow so that the magnetic field is going in the direction of the point on the arrow. You shoot the arrow through the center of a metal hoop, hanging from a tree. What will be the direction of the induced current in the hoop as the arrow leaves the far side of the hoop?

▷ PROBLEM 2.13

A magnetic field is coming straight up through the table in front of you. The field strength is increasing at a constant rate, $B = \left(0.5\frac{\mathrm{T}}{\mathrm{s}}\right) t$. You have a square loop of wire with a total resistance of 0.10 ohms and a length of 10cm per side. At what angle to the table should you prop of the loop so that the induced current in the loop is 40 mA.



▷ PROBLEM 2.14

An electromagnetic wave has an electric field amplitude of 500N/C and a wavelength of 600 m.
(a) What is the energy density of the wave?
(b) What is the energy flux density of the wave?
(c) What is the period of the wave?
(d) Write a function $E(x, t)$ that gives the electric field at each position x and time t.

▷ PROBLEM 2.15

Consider a laser striking the front of an aquarium. For what angles will the beam exit the side of the aquarium. You can ignore the glass and treat the aquarium as a cube of water. Assume that the aquarium goes on to infinity from the corner.

▷ PROBLEM 2.16

You form and image of an object with a lens with a focal length of 40cm. The image is formed 60cm from the lens. Where was the object? Draw the ray diagram with the three principle rays.

▷ PROBLEM 2.17

You place an object 14cm from a diverging lens with a focal length of -8 cm.
(a) What is the location of the image formed by the lens.
(b) Draw the three principle rays that show the location of the image.

▷ PROBLEM 2.18

Suppose that an electron has a speed of $727\frac{\text{m}}{\text{s}}$.
(a) What is the wavelength of the electron?
(b) Assuming that there is only kinetic energy what is the period of the electron?
(c) If the electron is sent through a double slit with a slit spacing of $d = 500\mu$m and a detector is placed at a screen $L = 2.00$m away from

the slits. How far y from the central maximum should you put the detector to have a minimum probability of detecting the electron?

▷ Problem 2.19

A particle with a mass of m and a charge q is accelerated from rest by an electric field through a potential difference of ΔV.

(a) Find an expression for the wavelength of the particle after it has been accelerated.

(b) Find the wavelength of an electron accelerated through $\Delta V = 1.5045\text{V}$.

(c) Find the wavelength of an electron accelerated through $n^2(1.5045\text{V})$ for some number n.

▷ Problem 2.20

Suppose that the energy levels of a system are $E_n = \varepsilon n^2$ for $n = 0, 1, 2$ or 3 and where $\varepsilon = 2\text{eV}$.

(a) What are the wavelengths of the photons that could possibly be emitted or absorbed by this system?

(b) The transition between what two states gives the shortest wavelength photon?

(c) The transition between what two states gives the longest wavelengths photon?

▷ Problem 2.21

There are two possible paths for a particle to arrive from a source to a detector. With both paths open 90 particles are detected per second. When path A is blocked there are 30 particles detected per second and when path B is blocked there are 20 particles detected per second.

(a) What is a possible phase difference between the two paths?

(b) If you move the detector what are the maximum and minimum number of particles you expect to detect per second?

▷ Problem 2.22

An electron is know to be trapped in a region that is 500 nm long. What is the least possible uncertainty in the velocity of the electron?

▷ Problem 2.23

If a nucleus emits an alpha particle, how is the nucleus different after the emission?

▷ Problem 2.24

You have a sample of radioactive material. You set up a detector to sense the emission of radiation. You measure the emission rate and find that you get 2000 emissions per second. You measure the emission rate one day later and find the emission rate is 1500 per second. What is the half life of the radioactive material?

A Hints

1.1 The area between the paths is two triangles, with the base of both triangles the distance between the slits, and the two heights add to L.

2.1 Use the equipartition theorem.

2.2 Think about thermal conductivity.

2.3 Intensity is power per area. Remember latent heat, and density.

2.4 When the planet is in equilibrium the power absorbed from the solar radiation is equal to the power emitted from the planet as thermal radiation.

2.5 Use Coulomb's Law.

2.6 Recall the relationship between electric field and electric potential, and the definition of electric potential.

2.8 Remember Kirchhoff's Rules.

2.9 The effective resistance would be useful here.

2.10 The magnetic force is always perpendicular to the velocity, in this case because the field is uniform it implies that the motion is a circle.

2.11 Remember the right hand rule.

2.12 Lenzs law.

2.13 Faraday's Law.

2.15 Snell's law.

2.16 Use the thin lens equation.

2.17 Thin lens equation.

2.18 Remember that the momentum is mv.

2.19 Use conservation of energy, to find the kinetic energy, then express the kinetic energy in terms of the momentum, that is $K = \frac{p^2}{2m}$. With the momentum you can find the wavelength.

2.20 Use conservation of energy.

2.21 Use addition of waves.

2.22 Use the uncertainty principle.

2.24 Use exponential decay.

§ A.1 Fundamental Constants

speed of light	c	$2.99792458 \times 10^8 \frac{\text{m}}{\text{s}}$	(exact)
Planck constant	h	$6.6260755(40) \times 10^{-34}\text{J} \cdot \text{s}$	
	hc	$1239.8424(93)\ \text{eV} \cdot \text{nm}$	
		$1240\ \text{eV} \cdot \text{nm}$	
	$\hbar$	$1.05457266(63) \times 10^{-34}\text{J} \cdot \text{s}$	
	$\hbar c$	$197.327053(59)\ \text{eV} \cdot \text{nm}$	
fundamental charge	e	$1.60217733(49) \times 10^{-19}\text{C}$	
mass of electron	m_e	$9.1093897(54) \times 10^{-31}\text{kg}$	
		$0.51099906(15)\ \text{MeV}/c^2$	
mass of proton	m_p	$1.672631(10) \times 10^{-27}\text{kg}$	
		$938.27231(28)\ \text{MeV}/c^2$	
Boltzman constant	k	$1.380658(12) \times 10^{-23}\text{J/K}$	
		$8.617385(73) \times 10^{-5}\text{eV/K}$	
Avogadro number	N_A	$6.0221367(36) \times 10^{23}$	
permeability of free space	μ_0	$4\pi \times 10^{-7}\text{N/A}^2$	(exact)
permittivity of free space	ϵ_0	$1/(\mu_0 c^2)$	(exact)
		$8.854187817 \times 10^{-12}\text{C}^2/\text{N} \cdot \text{m}^2$	
	$\frac{1}{4\pi\epsilon_0}$	$8.99 \times 10^9\text{N} \cdot \text{m}^2/\text{C}^2$	
gravitational constant	G	$6.67259(85) \times 10^{-11}\text{m}^2/\text{kg} \cdot \text{s}$	