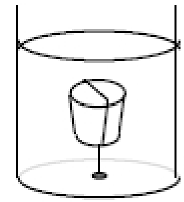
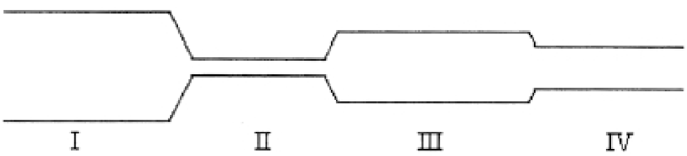
AP Physics Multiple Choice Practice – Fluid Mechanics

1. A cork has weight *mg* and density 25% of water's density. A string is tied around the cork and attached to the bottom of a water-filled container. The cork is totally immersed. Express the tension in the string in terms of the cork weight *mg*.
A) 0
B) mg
C) 2mg
D) 3mg



2. An ideal fluid flows through a long horizontal circular pipe. In one region of the pipe, it has radius R. The pipe then widens to radius 2R. What is the ratio of the fluid's speed in the region of radius R to the speed of the fluid in region with radius 2R?
A) 4 B) 2 C) ½ D) ¼

3. A fluid is forced through a pipe of changing cross section as shown. In which section would the pressure of the fluid be a minimum?



A) I B) II C) III D) IV

4. Three objects all float on top of water. They have the following relationships:
   - A and B have the same mass and same density but different shapes
   - B and C have the same volume and same shape
   - mass & density of C < mass & density of B

Three identical weights are tied to each object, and each is pulled completely beneath the water. Which object will displace the greatest amount of water?
A) A
B) B
C) C
D) All displace the same amount of water.

5. As a rock sinks deeper and deeper into water of constant density, what happens to the buoyant force on it?
A) It increases.
B) It remains constant.
C) It decreases.
D) It may increase or decrease, depending on the shape of the rock.

6. A piece of wood with a volume of 50 cm^3 is floating on water, and a piece of iron with a volume of 50 cm^3 is totally submerged. Which has the greater buoyant force on it?
A) The wood.
B) The iron.
C) Both have the same buoyant force.
D) Cannot be determined without knowing their densities.

7. Salt water is more dense than fresh water. A ship floats in both fresh water and salt water. Compared to the fresh water, the amount of water displaced by the ship when it i in the salt water is
A) more.
B) less.
C) the same.
D) Cannot be determined from the information given.

8. Water flows through a horizontal pipe. The diameter of the pipe at point B is larger than at point A. Where is the water pressure greater?
   A) Point A
   B) Point B
   C) Same at both A and B
   D) Cannot be determined from the information given.

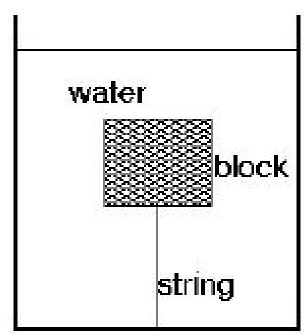
9. Liquid flows through a 4 cm diameter pipe at 1.0 m/s. There is a 2 cm diameter constriction in the line. What is the velocity in this constriction?
   A) 0.25 m/s B) 0.50 m/s C) 2 m/s D) 4 m/s

10. A copper block is connected to a string and submerged in a container of water.
   Position 1: The copper is completely submerged, but just under the surface of the water.
   Position 2: The copper is completely submerged, mid-way between the water surface and the bottom of the container.
   Position 3: The copper is completely submerged, but just above the bottom surface of the container.

   Assume that the water is incompressible. What is the ranking of the buoyant forces (B) acting on the copper blocks for these positions, from least to greatest?
   (A) $B_1 < B_2 < B_3$
   (B) $B_3 < B_2 < B_1$
   (C) $B_1 = B_2 = B_3$
   (D) $B_1 < B_2 = B_3$

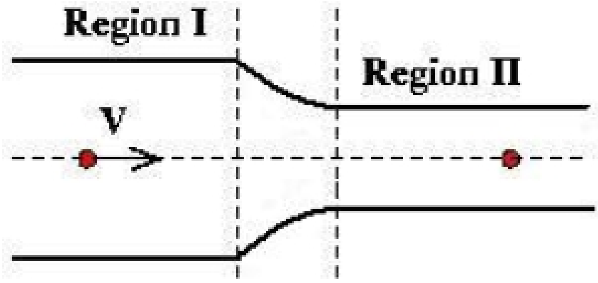
11. Two objects labeled K and L have equal mass but densities $0.95D_o$ and D_o, respectively. Each of these objects floats after being thrown into a deep swimming pool. Which is true about the buoyant forces acting on these objects?
   (A) The buoyant force is greater on Object K since it has a lower density and displaces more water.
   (B) The buoyant force is greater on Object K since it has lower density and lower density objects always float "higher" in the fluid.
   (C) The buoyant force is greater on Object L since it is denser than K and therefore "heavier."
   (D) The buoyant forces are equal on the objects since they have equal mass.

12. A block is connected to a light string attached to the bottom of a large container of water. The tension in the string is 3.0 N. The gravitational force from the earth on the block is 5.0 N. What is the block's volume?
   (A) $2.0\times10^{-4}\ m^3$
   (B) $3.0\times10^{-4}\ m^3$
   (C) $5.0\times10^{-4}\ m^3$
   (D) $8.0\times10^{-4}\ m^3$



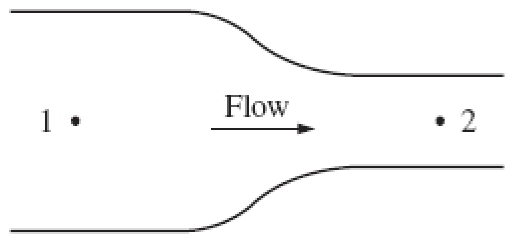
13. A cube of unknown material and uniform density floats in a container of water with 60% of its volume submerged. If this same cube were placed in a container of oil with density 800 kg/m^3, what portion of the cube's volume would be submerged while floating?
   (A) 33% (B) 50% (C) 58% (D) 75%

14. The speed of an ideal fluid is marked as it moves along a horizontal streamline through a pipe, as shown in the figure. In Region I, the speed of the fluid on the streamline is *V*. The cylindrical, horizontal pipe narrows so that the radius of the pipe in Region II is half of what it was in Region I. What is the speed of the marked fluid when it is in Region II?



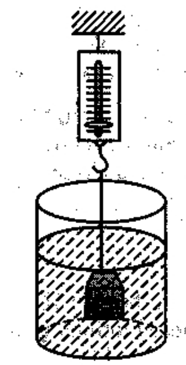
(A) 4V (B) 2V (C) V/2 (D) V/4

15. A fluid flows steadily from left to right in the pipe shown. The diameter of the pipe is less at point 2 then at point 1, and the fluid density is constant throughout the pipe. How do the velocity of flow and the pressure at points 1 and 2 compare?



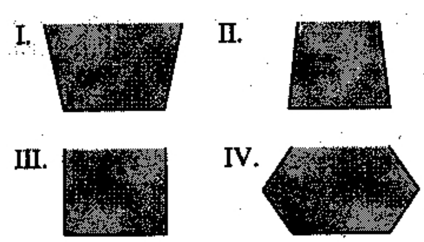
	Velocity	Pressure
(A)	$v1 < v2$	$p1 = p2$
(B)	$v1 < v2$	$p1 > p2$
(C)	$v1 = v2$	$p1 < p2$
(D)	$v1 > v2$	$p1 = p2$

16. The figure shows an object of mass 0.4 kg that is suspended from a scale and submerged in a liquid. If the reading on the scale is 3 N, then the buoyant force that the fluid exerts on the object is most nearly



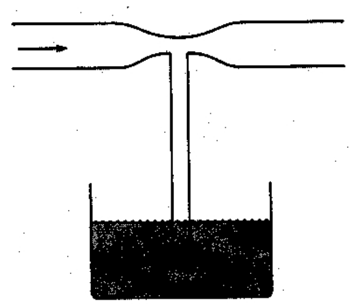
(A) 1.3 N
(B) 1.0N
(C) 0.75 N
(D) 0.33 N

17. Each of the beakers shown is filled to the same depth *h* with liquid of density *ρ*. The area *A* of the flat bottom is the same for each beaker. Which of the following ranks the beakers according to the net downward force exerted by the liquid on the flat bottom, from greatest to least force?



(A) I, III, II, IV
(B) I, IV, III, II
(C) II, III, IV, I
(D) None of the above, the force on each is the same.

18. **Multiple Correct:** A T-shaped tube with a constriction is inserted in a vessel containing a liquid, as shown. What happens if air is blown through the tube from the left, as shown by the arrow in the diagram? Select two answers.



(A) The liquid level in the tube rises to a level above the surface of the liquid in the surrounding tube
(B) The liquid level in the tube falls below the level of the surrounding liquid
(C) The pressure in the liquid in the constricted section increases.
(D) The pressure in the liquid in the constricted section decreases.

19. One cubic centimeter of iron (density ~7.8 g/cm^3) and 1 cubic centimeter of aluminum (density ~2.7 g/cm^3) are dropped into a pool, and they sink to the bottom. Which has the larger buoyant force on it?
(A) iron (B) aluminum (C) both are the same. (D) neither has a buoyant force on it

20. One kilogram of iron (density ~7.8 g/cm^3) and 1 kilogram of aluminum (density ~2.7 g/cm^3) are dropped into a pool, and they sink to the bottom. Which has the larger buoyant force on it?
(A) iron (B) aluminum (C) both are the same. (D) neither has a buoyant force on it

21. Find the approximate minimum mass needed for a spherical ball with a 40 cm radius to sink in a liquid of density 1.4x10^3 kg/m^3
(A) 37.5 kg (B) 375 kg (C) 3750 kg (D) 37500 kg

22. A horizontal pipe of radius 7R carries a uniformly dense liquid to a spigot of radius R, where it has a speed of V. What is the speed of the liquid in the larger diameter pipe?
(A) 0.02V (B) 0.11V (C) V (D) 49V

23. The pressure in a pipe carrying a liquid with a density of ρ and an initial velocity v at the inlet is P, which is y meters lower than its outlet, which has a velocity of 2v. In these terms, what is the final pressure?

$$(A)\ \frac{P}{2}\rho\left(3v^2+2gy\right)$$

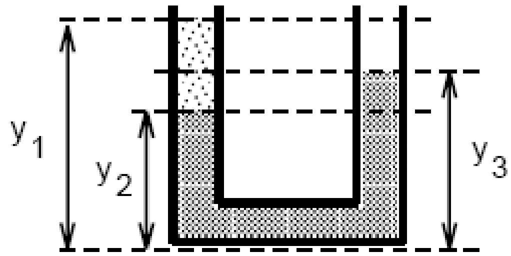
$$(B)\ P-\frac{1}{2}\rho\left(3v^2+2gy\right)$$

$$(C)\ P+\frac{1}{2}\rho\left(-3v^2+\rho gy\right)$$

$$(D)\ \frac{\frac{1}{2}\rho\left(v^2-4v^2\right)-\rho gy}{P}$$

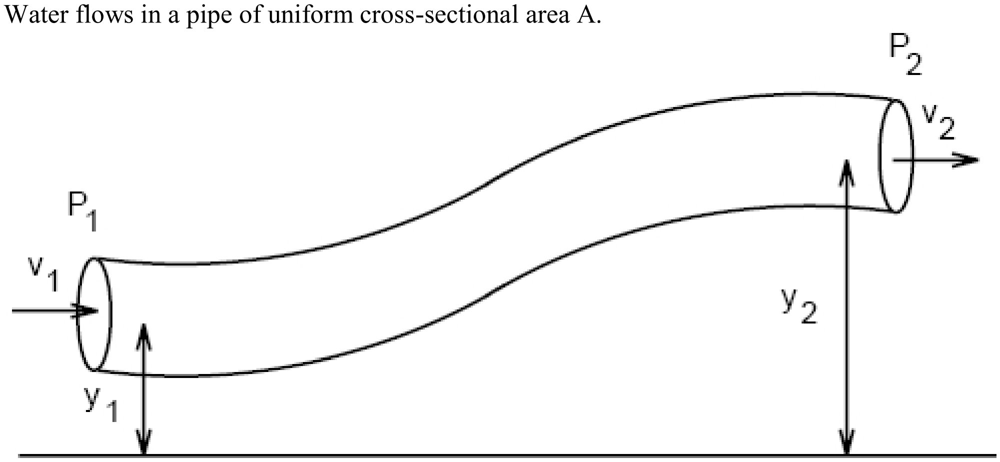
24. A block of mass m, density ρ_B , and volume V is completely submerged in a liquid of density ρ_L. The density of the block is greater than the density of the liquid. The block
(A) floats, because $\rho_B > \rho_L$
(B) experiences a buoyant force equal to ρ_B gV.
(C) experiences a buoyant force equal to ρ_L gV.
(D) experiences a buoyant force equal to m_B g

25. **Multiple Correct:** In the open manometer shown, water occupies a part of the left arm, from a height of y_1 to a height of y_2. The remainder of the left arm, the bottom of the tube, and the right arm to a height of y_3 are filled with mercury.



Which of the following is correct? (Select two answers.)
(A) the pressure at a height y_3 is the same in both arms.
(B) the pressure at a height y_2 is the same in both arms.
(C) the pressure at the bottom of the right arm is the same as at the bottom of the left arm.
(D) the pressure at a height y_3 is less in the left arm than in the right arm.

26. Water flows in a pipe of uniform cross-sectional area A.

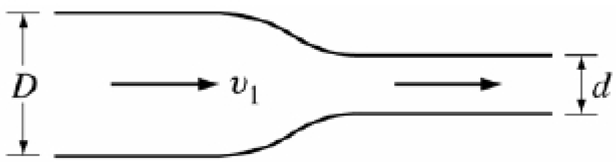


The pipe changes height from $y_1 = 2$ meters to $y_2 = 3$ meters. Since the areas are the same, we can say $v_1 = v_2$. Which of the following is true?
(A) $P_1 = P_2 + \rho g(y_2 - y_1)$
(B) $P_1 = P_2$
(C) $P_1 = 0$
(D) $P_2 = 0$

27. A vertical force of 30 N is applied uniformly to a flat button with a radius of 1 cm that is lying on a table. Which of the following is the best order of magnitude estimate for the pressure applied to the button?
(A) 10^2 Pa
(B) 10^3 Pa
(C) 10^4 Pa
(D) 10^5 Pa

28. A ball that can float on water has mass 5.00 kg and volume 2.50×10^{-2} m^3. What is the magnitude of the downward force that must be applied to the ball to hold it motionless and completely submerged in fresh water of density 1.00×10^3 kg/m^3?
(A) 20.0 N
(B) 25.0 N
(C) 30.0 N
(D) 200 N

29. Water flows through the pipe shown. At the larger end, the pipe has diameter D and the speed of the water is v_1 .



What is the speed of the water at the smaller end, where the pipe has diameter d ?

$(A)\ \frac{d}{D}v_1$ $(B)\ \frac{D}{d}v_1$ $(C)\ \frac{d^2}{D^2}v_1$ $(D)\ \frac{D^2}{d^2}v_1$

AP Physics Free Response Practice – Fluids

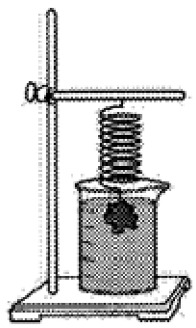
2002B6.

In the laboratory, you are given a cylindrical beaker containing a fluid and you are asked to determine the density ρ of the fluid. You are to use a spring of negligible mass and unknown spring constant k attached to a stand. An irregularly shaped object of known mass *m* and density *D* ($D >> \rho$) hangs from the spring. You may also choose from among the following items to complete the task.

- A metric ruler
- A stopwatch
- String

(a) Explain how you could experimentally determine the spring constant *k*.

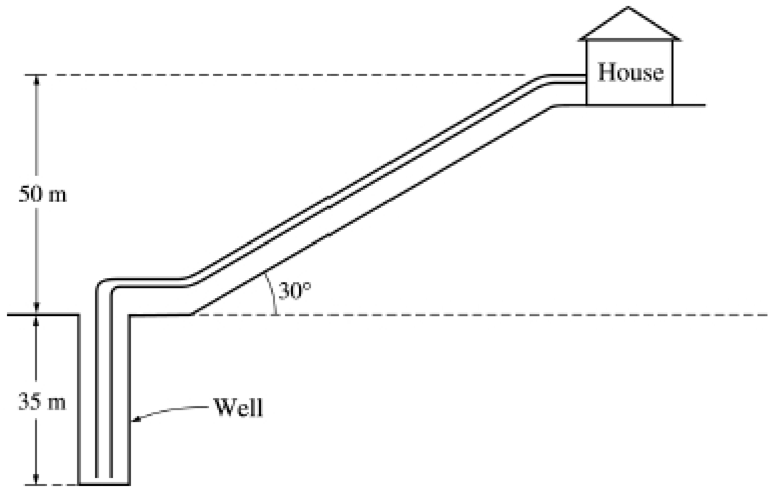
(b) The spring-object system is now arranged so that the object (but none of the spring) is immersed in the unknown fluid, as shown. Describe any changes that are observed in the spring-object system and explain why they occur.



(c) Explain how you could experimentally determine the density of the fluid.

(d) Show explicitly, using equations, how you will use your measurements to calculate the fluid density ρ. Start by identifying any symbols you use in your equations.

Symbol	Physical quantity



B2003B6.

A pump, submerged at the bottom of a well that is 35 m deep, is used to pump water uphill to a house that is 50 m above the top of the well, as shown above. The density of water is 1,000 kg/m^3. Neglect the effects of friction, turbulence, and viscosity.

(a) Residents of the house use 0.35 m^3 of water per day. The day's pumping is completed in 2 hours during the day.

i. Calculate the minimum work required to pump the water used per day

ii. Calculate the minimum power rating of the pump.

(b) In the well, the water flows at 0.50 m/s and the pipe has a diameter of 3.0 cm. At the house the diameter of the pipe is 1.25 cm.

i. Calculate the flow velocity at the house when a faucet in the house is open.

ii. Calculate the pressure at the well when the faucet in the house is open.

2003B6.
A diver descends from a salvage ship to the ocean floor at a depth of 35 m below the surface. The density of ocean water is 1.025×10^3 kg/m^3.

(a) Calculate the gauge pressure on the diver on the ocean floor.

(b) Calculate the absolute pressure on the diver on the ocean floor.

The diver finds a rectangular aluminum plate having dimensions 1.0 m x 2.0 m x 0.03 m. A hoisting cable is lowered from the ship and the diver connects it to the plate. The density of aluminum is 2.7×10^3 kg/m^3. Ignore the effects of viscosity.

(c) Calculate the tension in the cable if it lifts the plate upward at a slow, constant velocity.
(d) Will the tension in the hoisting cable increase, decrease, or remain the same if the plate accelerates upward at 0.05 m/s^2?

____ increase ____ decrease ____ remain the same

Explain your reasoning.

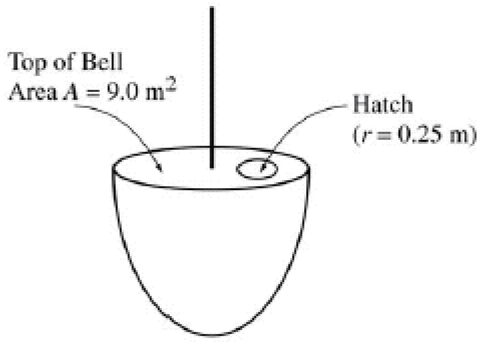
2004B2.
While exploring a sunken ocean liner, the principal researcher found the absolute pressure on the robot observation submarine at the level of the ship to be about 413 atmospheres. The inside of the submarine is kept at atmospheric pressure. The density of seawater is 1025 kg/m^3 .
(a) Calculate the gauge pressure on the sunken ocean liner.
(b) Calculate the depth of the sunken ocean liner.
(c) Calculate the magnitude of the net force due to the fluid pressures only on a viewing port of the submarine at this depth if the viewing port has a surface area of 0.0100 m^2 .
(d) What prevents the ‘net force’ found in part c from accelerating and moving the viewing port.

Suppose that the ocean liner came to rest at the surface of the ocean before it started to sink. Due to the resistance of the seawater, the sinking ocean liner then reached a terminal velocity of 10.0 m/s after falling for 30.0 s.

(e) Determine the magnitude of the average acceleration of the ocean liner during this period of time.

(f) Assuming the acceleration was constant, calculate the distance *d* below the surface at which the ocean liner reached this terminal velocity.

(g) Calculate the time *t* it took the ocean liner to sink from the surface to the bottom of the ocean.



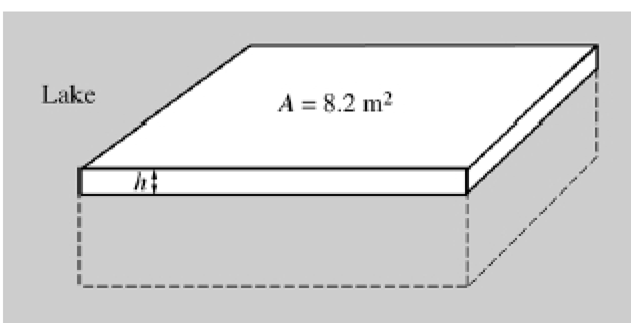
B2004B2.

The experimental diving bell shown above is lowered from rest at the ocean's surface and reaches a maximum depth of 80 m. Initially it accelerates downward at a rate of 0.10 m/s^2 until it reaches a speed of 2.0 m/s, which then remains constant. During the descent, the pressure inside the bell remains constant at 1 atmosphere. The top of the bell has a cross-sectional area A = 9.0 m^2. The density of seawater is 1025 kg/m^3.

(a) Calculate the total time it takes the bell to reach the maximum depth of 80 m.
(b) Calculate the weight of the water on the top of the bell when it is at the maximum depth.
(c) Calculate the absolute pressure on the top of the bell at the maximum depth.

On the top of the bell there is a circular hatch of radius $r = 0.25$ m.
(d) Calculate the minimum force necessary to lift open the hatch of the bell at the maximum depth.
(e) What could you do to reduce the force necessary to open the hatch at this depth? Justify your answer.

2005B5.

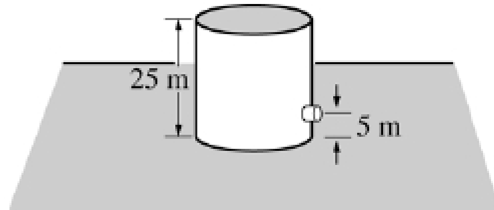


Note: Figure not drawn to scale.

A large rectangular raft (density 650 kg/m^3) is floating on a lake. The surface area of the top of the raft is 8.2 m^2 and its volume is 1.80 m^3. The density of the lake water is 1000 kg/m^3.
(a) Calculate the height h of the portion of the raft that is above the surrounding water.
(b) Calculate the magnitude of the buoyant force on the raft and state its direction.
(c) If the average mass of a person is 75 kg, calculate the maximum number of people that can be on the raft without the top of the raft sinking below the surface of the water. (Assume that the people are evenly distributed on the raft.)

B2005B5.

A large tank, 25 m in height and open at the top, is completely filled with saltwater (density 1025 kg/m^3). A small drain plug with a cross-sectional area of 4.0×10^{-5} m^2 is located 5.0 m from the bottom of the tank.



The plug breaks loose from the tank, and water flows from the drain.

(a) Calculate the force exerted by the water on the plug before the plug breaks free.

(b) Calculate the speed of the water as it leaves the hole in the side of the tank.

(c) Calculate the volume flow rate of the water from the hole.

2007B4.

The large container shown in the cross section is filled with a liquid of density 1.1×10^3 kg/m^3. A small hole of area 2.5×10^{-6} m^2 is opened in the side of the container a distance h below the liquid surface, which allows a stream of liquid to flow through the hole and into a beaker placed to the right of the container. At the same time, liquid is also added to the container at an appropriate rate so that h remains constant. The amount of liquid collected in the beaker in 2.0 minutes is 7.2×10^{-4} m^3.

(a) Calculate the volume rate of flow of liquid from the hole in m3 s.

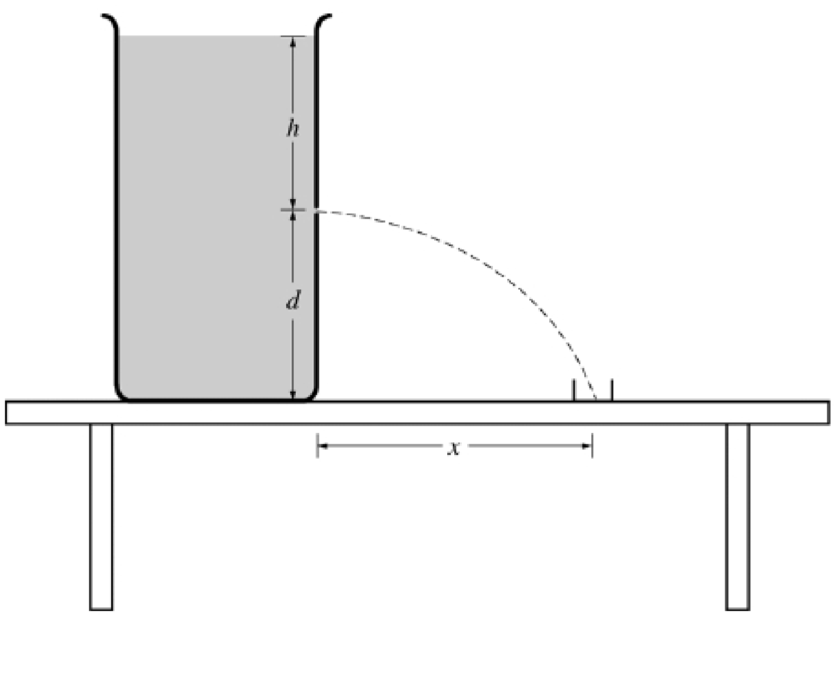
(b) Calculate the speed of the liquid as it exits from the hole.

(c) Calculate the height h of liquid needed above the hole to cause the speed you determined in part (b).

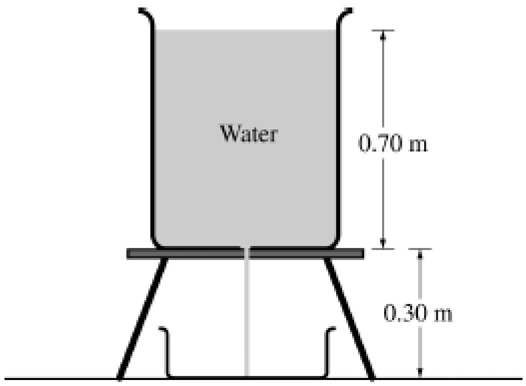
(d) Suppose that there is now less liquid in the container so that the height h is reduced to $h/2$. In relation to the collection beaker, where will the liquid hit the tabletop?

____ Left of the beaker ____ In the beaker ____ Right of the beaker

Justify your answer.



B2007B4.



A cylindrical tank containing water of density 1000 kg/m^3 is filled to a height of 0.70 m and placed on a stand as shown in the cross section above. A hole of radius 0.0010 m in the bottom of the tank is opened. Water then flows through the hole and through an opening in the stand and is collected in a tray 0.30 m below the hole. At the same time, water is added to the tank at an appropriate rate so that the water level in the tank remains constant.

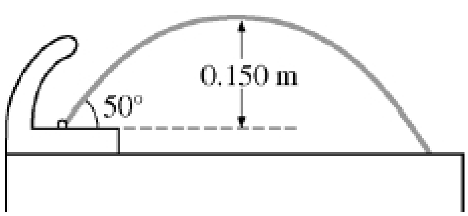
(a) Calculate the speed at which the water flows out from the hole.

(b) Calculate the volume rate at which water flows out from the hole.

(c) Calculate the volume of water collected in the tray in t = 2.0 minutes.

(d) Calculate the time it takes for a given droplet of water to fall 0.25 m from the hole.

2008B4.



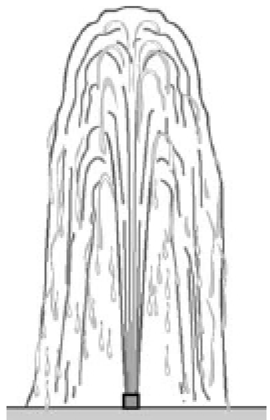
A drinking fountain projects water at an initial angle of 50° above the horizontal, and the water reaches a maximum height of 0.150 m above the point of exit. Assume air resistance is negligible.

(a) Calculate the speed at which the water leaves the fountain.

(b) The radius of the fountain's exit hole is 4.00 x 10^{-3} m. Calculate the volume rate of flow of the water.

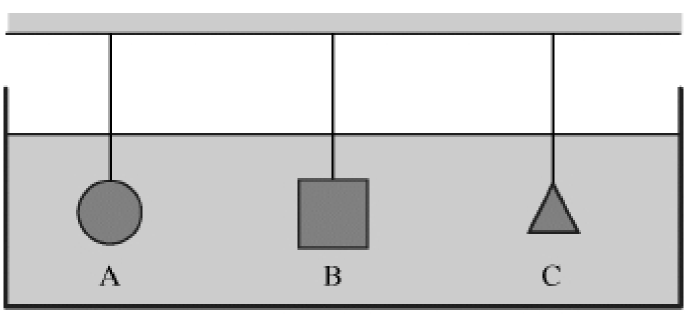
(c) The fountain is fed by a pipe that at one point has a radius of 7.00 x 10^{-3} m and is 3.00 m below the fountain's opening. The density of water is 1.0 x 10^3 kg/m^3. Calculate the gauge pressure in the feeder pipe at this point.

B2008B4.



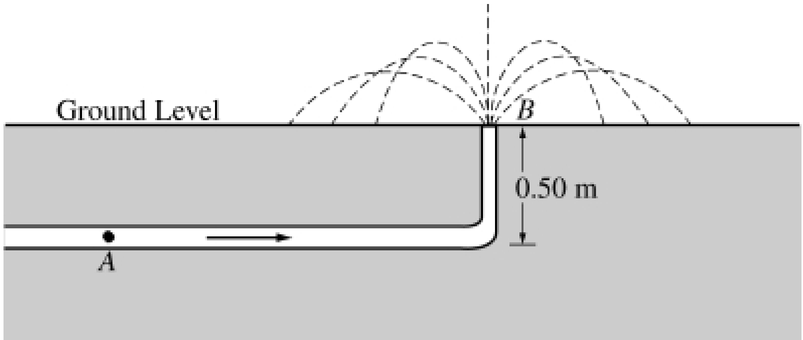
A fountain with an opening of radius 0.015 m shoots a stream of water vertically from ground level at 6.0 m/s. The density of water is 1000 kg/m^3.
(a) Calculate the volume rate of flow of water.
(b) The fountain is fed by a pipe that at one point has a radius of 0.025 m and is 2.5 m below the fountain's opening. Calculate the absolute pressure in the pipe at this point.
(c) The fountain owner wants to launch the water 4.0 m into the air with the same volume flow rate. A nozzle can be attached to change the size of the opening. Calculate the radius needed on this new nozzle.

2009B5.



Three objects of identical mass attached to strings are suspended in a large tank of liquid, as shown above.
(a) Must all three strings have the same tension?
____ Yes ____ No
Justify your answer.
Object A has a volume of 1.0×10^{-5} m^3 and a density of 1300 kg m^3. The tension in the string to which object A is attached is 0.0098 N.
(b) Calculate the buoyant force on object A.
(c) Calculate the density of the liquid.
(d) Some of the liquid is now drained from the tank until only half of the volume of object A is submerged. Would the tension in the string to which object A is attached increase, decrease, or remain the same?
____ Increase ____ Decrease ____ Remain the same
Justify your answer.

B2009B3.



An underground pipe carries water of density 1000 kg/m^3 to a fountain at ground level, as shown above. At point A, 0.50 m below ground level, the pipe has a cross-sectional area of 1.0×10^{-4} m^2. At ground level, the pipe has a cross-sectional area of 0.50×10^{-4} m^2. The water leaves the pipe at point B at a speed of 8.2 m/s.

(a) Calculate the speed of the water in the pipe at point A.

(b) Calculate the absolute water pressure in the pipe at point A.

(c) Calculate the maximum height above the ground that the water reaches upon leaving the pipe vertically at ground level, assuming air resistance is negligible.

(d) Calculate the horizontal distance from the pipe that is reached by water exiting the pipe at 60° from the level ground, assuming air resistance is negligible.

Supplemental Problems

SUP1. A block of wood has a mass of 12 kg and dimensions 0.5 m by 0.2 m by 0.2 m.

(a) Find the density ρ_o of the wooden block.

(b) If the block is placed in water (ρ = 1000 kg/m^3) with the square sides parallel to the water surface, how far beneath the surface of the water is the bottom of the block?

(c) A weight is placed on the top of the block. The block sinks to a point that the top of the block is exactly even with the water surface. Find the mass of the added weight.

SUP2. A tapered horizontal pipe carries water from one building to another on the same level. The wider end has a cross-sectional area of 4 m^2. The narrower end has a cross-sectional area of 2 m^2. Water enters the wider end at a velocity of 10 m/sec.

(a) What is the speed of the water at the narrow end of the pipe?

(b) The gauge pressure of the water at the wide end of the pipe is 2×10^5 pascals. Using Bernoulli's equation, find the gauge pressure at the narrow end of the pipe.

SUP3. A small airplane has wings with surface area 9 m^2 each. The speed of the air across the top of the wing is 50 m/sec, and across the bottom of the wing, 40 m/sec. Take the density of air to be 1.2 kg/m^3.

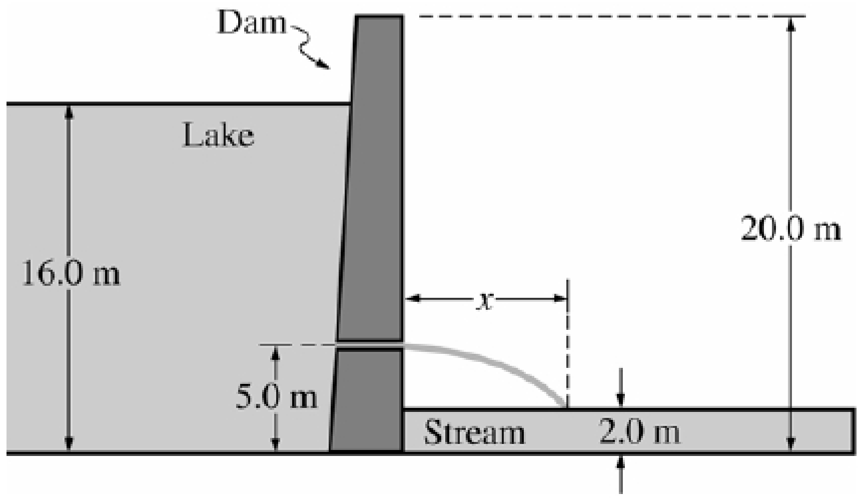
(a) Find the difference in the pressure between the top and the bottom of the wing.

(b) i) Find the net lift upward on the plane.

ii) If there is no other lift on the plane, what would be the mass of the plane? Assume the plane is not accelerating up or down.

SUP4. A block of wood floats in water, with 2/3 of it submerged. The wood is then placed in oil, and 9/10 of it is submerged. Find the density of the wood, and of the oil.

SUP5.



A 20 m high dam is used to create a large lake. The lake is filled to a depth of 16 m as shown above. The density of water is 1000 kg/m^3 .

(a) Calculate the absolute pressure at the bottom of the lake next to the dam.

A release valve is opened 5.0 m above the base of the dam, and water exits horizontally from the valve.
(b) Use Bernoulli's equation to calculate the initial speed of the water as it exits the valve.

(c) The stream below the surface of the dam is 2.0 m deep. Assuming that air resistance is negligible, calculate the horizontal distance *x* from the dam at which the water exiting the valve strikes the surface of the stream.

(d) Suppose that the atmospheric pressure in the vicinity of the dam increased. How would this affect the initial speed of the water as it exits the valve?

___It would increase. ____It would decrease. ____It would remain the same.
Justify your answer.

ANSWERS - AP Physics Multiple Choice Practice – Fluids

	Solution	Answer
1.	FBD has F_t pointing down F_b pointing up and weight (mg) down. $F_{net} = 0$ $F_b - F_t - mg = 0$ The buoyant force is given by the weight of the displaced water. Since the waters displaced volume is equal to the corks displaced volume and the water weight for the same volume would be 4 times heavier (based on the given cork weight = 25% water weight) compared to the cork, the buoyant force is equal to 4 x the cork weight = 4mg. Using the force equation created initially. $F_t = F_b - mg = 4mg - mg = 3mg$	D
2.	Using fluid continuity. $A_1v_1 = A_2v_2$ $\pi R^2 v_1 = \pi(2R)^2 v_2$ $v_1 = 4\ v_2$	A
3.	This is based on two principles. 1 – Bernoulli's principle says that when speed increases pressure drops. Second, continuity says more area means less speed based on $A_1v_1 = A_2v_2$ So the smallest area would have the largest speed and therefore most pressure drop.	B
4.	Since A and B have the same mass and density, they have the same volume. C has the same volume as A and B since it's the same shape as B. So all three objects have the same volume. When submerged, they will all displace the same amount of water and therefore all have the same buoyant force acting on them. *Note: if the objects were floating instead of submerged then the heavier ones would have larger buoyant forces*.	D
5.	Buoyant force is equal to weight of displaced fluid. Since the density is constant and the volume displaced is always the same, the buoyant force stays constant	B
6.	The wood is floating and is only partially submerged. It does not displace a weight of water related to its entire volume. The iron however is totally submerged and does displace a weight of water equal to its entire volume. Since the iron displaces more water, it has a larger buoyant force acting on it.	B
7.	For floating objects, the weight of the displaced fluid equals the weight of the object. For a more dense fluid, less of that fluid needs to be displaced to create a fluid weight equal to the weight of the object. Since the salt water is more dense, it will not need as much displaced.	B
8.	More area → less speed → more pressure	B
9.	Flow continuity. $A_1v_1 = A_2v_2$ $\pi(0.02)^2(1) = \pi(0.01)^2 v_2$	D
10.	Buoyant force is based on how much weight of water is displaced. Since all three are completely submerged they all displace the same amount of water so have equal buoyant forces.	C
11.	For floating objects, the buoyant force equals the weight of the objects. Since each object has the same weight, they must have the same buoyant force to counteract that weight and make them float. *IF the equal mass objects sunk, then the one with the smaller density would have a larger volume and displace more water so have a larger buoyant force. But that is not the case here.*	D
12.	Three forces act on the block, F_t down, mg down and F_b up. $F_{net} = 0$ $F_b - F_t - mg = 0$ $F_b - 3 - 5 = 0$ $F_b = 8$ N – weight of displaced water $= \rho_{h20} V_{disp}\, g$ $8 = (1000)\ V\ (10)$ → $V = 0.0008\ m^3$	D
13.	For floating objects $mg = F_b$ $\rho_{obj} V_{obj}\, g = \rho_{h20} V_{disp}\, g$ $\rho_{obj}\ (V) g = 1000\ (0.6V)\ g$ $\rho_{obj} = 600$ In oil the same is true $\rho_{obj} V_{obj}\, g = \rho_{oil} V_{disp}\, g$ $(600)Vg = (800)\ x\%V\ g$ $x\% = 0.75$	D

14. Using fluid continuity. $A_1v_1 = A_2v_2$ $\pi R^2 v_1 = \pi(2R)^2 v_2$ $v_1 = 4\ v_2$ A

15. Based on the continuity principle, less area means more speed and based on Bernoulli's principle, more speed means less pressure B

16. The weight of the object The weight of the mass is 4N. The scale reading apparent weight is 3N so there must be a 1N buoyant force acting to produce this result. B

17. . Since the pressure in a fluid is only dependent on the depth, they all have the same fluid pressure at the base. Since all of the bases have the same area and the same liquid pressure there, the force of the liquid given by P=F/A would be the same for all containers. *Note: IF instead this question asked for the pressure of the container on the floor below it, the container with more total mass in it would create a greater pressure, but that is not the case here.* D

18. As the fluid flows into the smaller area constriction, its speed increases and therefore the pressure drops. Since the pressure in the constriction is less than that outside at the water surface, fluid is forced up into the lower tube. A,D

19. Both objects are more dense than water and will sink in the pool. Since both have the same volume, they will displace the same amount of water and will have the same buoyant forces. C

20. Again both samples sink. Also, both samples have the same mass but different densities. For the same mass, a smaller density must have a larger volume, and the larger volume displaces more water making a larger buoyant force. So the smaller density with the larger volume has a larger buoyant force. B

21. V of this ball is $4/3\ \pi\ r^3 = 4/3\ \pi\ (0.4)^3 = 0.2681\ m^3$. For the ball to just sink, it is on the verge of floating, meaning the weight of the ball equals the buoyant force of the fully submerged ball. B
$mg = \rho_{fl} V_{disp}\, g$ $m\,(10) = 1400\,(0.2681)\,(10)$ $m = 375$ kg

22. Using fluid continuity. $A_1v_1 = A_2v_2$ $\pi(7R)^2 v_1 = \pi(R)^2 V$ $v_1 = V / 49$ A

23. The fluid flow is occurring in a situation similar to the diagram for question #27. B
Apply Bernoulli's equation. $P_1 + \rho g y_1 + ½\, \rho v_1^2 = P_2 + \rho g y_2 + ½\, \rho v_2^2$
$P + 0 + ½\, \rho v^2 = P_2 + \rho g y + ½\, \rho\, (2v)^2$
$P_2 = P + ½\, \rho v^2 - ½\, 4 \rho v^2 - \rho g y$ $= P - 3/2\, \rho v^2 - \rho g y$

24. Definition of buoyant force C

25. The relevant equation is $P = Po + \rho g h$
Answer (a) is wrong, because at y1 on both arms, the pressure is just the atmospheric pressure. The pressure in the right arm at y3 is still just atmospheric, but on the left, it is atmospheric plus $\rho g(y1 - y3)$. That rules out (a). The pressure at the bottom of the tube is everywhere the same (Pascal's principle), which rules out (c), and at the same time, tells us (b) is right. At y2, we can say $P = Pbottom - \rho_{Hg} gy2$ on both sides, so the pressure is equal. Answer (d) is wrong because at y3, the right arm is supporting only the atmosphere, while the left arm is supporting the atmosphere plus $\rho_{H20}\, gh$. Finally, (e) is silly because both arms at height y1 are at atmospheric pressure. B,C

26. Apply Bernoulli's equation. $P_1 + \rho g y_1 \cancel{+ ½\, \rho v_1^2} = P_2 + \rho g y_2 + \cancel{½\, \rho v_2^2}$ A
$P_1 = P_2 + \rho g(y_2 - y_1)$

27. $P = F / A = 30 / \pi r^2$ … use 3 for π since its an estimate … $30 / (3*(.01)^2) = 100000$ Pa D

28. For the object to be completely submerged there would be three forces acting. F_b up, mg down and F_{push} down. $F_b = F_{push} + mg$ $F_{push} = F_b - mg$ D

$F_{push} = p_{h20}\, V_{disp}\, g - mg$

$= (1000)(2.5\text{x}10^{-2})(10) - (5)(10) = 200$ N

29. Using fluid continuity. $A_1v_1 = A_2v_2$ $\pi(D/2)^2v_1 = \pi(d/2)^2v_2$ solve for v_2 D

2002B6.

a) Example 1: Measure the unstretched length of the spring. Hang it with the object at rest and measure the stretched length. Call the difference in these lengths Δx. Equating the weight of the object and the force exerted by the extended spring gives $mg = k\Delta x$ from which k can be determined.

Example 2: Set the hanging mass into oscillation. Determine the period T by timing n oscillations and dividing that time by n. The equation $T = 2\pi\sqrt{m / k}$ can then be used to find k.

b) The spring is stretched less when the object is at rest in the fluid. The fluid exerts an upward buoyant force on the object. Since the net force on the object is still zero, the spring does not need to exert as much force as before and thus stretches less.

c&d)

1) Measure the length of the spring when the object is immersed in the liquid, and subtract the unstretched length to determine the amount the spring is stretched. This will allow calculation of the force exerted by the spring on the object.
2) The volume of fluid displaced is equal to the volume of the object, which can be determined from the given mass and density of the object.
3) The buoyant force on the object is equal to the difference of the object's weight and the force exerted by the spring.
4) The buoyant force also equals the weight of the displaced fluid, which equals the product of the fluid density, displaced volume, and g.

Symbol	Quantity
ρ	fluid density
V	object volume = displaced water volume
g	acceleration of gravity
m	mass of object
x	spring stretch in air
x_w	spring stretch in water

First solving for k in air. $mg = kx$

Then in the fluid. $F_{sp} = kx_w$

$F_{net} = 0$ $\quad$ $F_b = mg - F_{sp}$ $\quad$ $\rho Vg = mg - kx_w$ $\quad$ $\rho Vg = mg - (mg / x)\, x_w$ $\quad$ solve for ρ

B2003B6.

a) i) The total mass of water moved can be found with the density and volume $m = \rho V = (1000)(0.35) = 350$ kg of water. This water is moved a distance 85 m so the work done to move it is $W=Fd = (350)(9.8)(85) = 291{,}500$ J.

ii) The force needed to move the water = the weight of the water (mg).
Using. $P = Fd / t = (350)(9.8)(85) / (2\text{hrs} * 3600 \text{ s/hr}) = 40.5$ W

b) i) Using fluid continuity. $A_1v_1 = A_2v_2$ $\pi(.03/2)^2(0.5) = \pi(0.0125/2)^2v_2$ $v_2 = 2.88$ m/s

ii) Apply Bernoulli's equation. $P_1 + \rho gy_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho gy_2 + \frac{1}{2}\rho v_2^2$
$y_1 = 0$ P_2 = atmospheric (open faucet)

$P_1 + 0 + \frac{1}{2}(1000)(0.5)^2 = 1.01\text{x}10^5 + (1000)(9.8)(85) + \frac{1}{2}(1000)(2.88)^2$ $P_1 = 938000$ Pa

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2003B6.

a) $P = \rho gh = (1025)(9.8)(35) = 351{,}600$ Pa

b) $P_{abs} = P_o + \rho gh = 1.01\text{x}10^5 + 343{,}000 = 452{,}600$ Pa

c) The FBD has three forces acting on it. The upwards lifting force, the upwards buoyant force and the downwards weight, mg. Constant velocity → $F_{net} = 0$
$F_t + F_b - mg = 0$ $F_t = mg - F_b$ $F_t = (\rho_{obj}V_{obj})g - (\rho_{h20}V_{disp})g$ $V_{disp} = V_{obj}$ call it V

→ $F_t = Vg(\rho_{al} - \rho_{h20}) = (1\text{x}2\text{x}0.03)(9.8)(2700 - 1025) = 985$ N

d) $F_t + F_b - mg = ma$ $F_t = mg - F_b + ma$. Comparing this tension equation to the one in part c you see that the tension will <u>increase</u> since the quantity "ma" is being added here

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2004B2.

a) $P_{abs} = P_o + P_{gauge}$ 413 atm = 1 atm – P_{gauge} P_{gauge} = 412 atm

b) $P_{gauge} = \rho gh$ $412(1.01\text{x}10^5) = 1024\ (9.8)(h)$ h = 4140 m

c) The fluid pressures acting are the outside water pressure (which includes the atmosphere at the surface acting down on it) and, the inside air pressure which is atmospheric. Since the atmospheric pressure acts both inside and is also included in the water pressure, the net force due to fluid pressure can be found by using the water's gauge pressure since the air pressures effectively cancel each other out.
$P_{gauge} = F/A$ $412(1.01\text{x}10^5) = F / 0.01$ F = 416,000 N

d) The force from c is not the true net force. The actual net force is zero as the window is at rest. This force from c is due to fluid pressures and is resisted by normal forces acting on the edges of the window where it is connected to the submarine.

e) $v_f = v_i + at$ $10 = 0 + a(30)$ $a = 0.33\ \text{m/s}^2$

f) $d = v_it + ½\ at^2$ $d = 0 + ½\ (0.33)(30)^2$ d = 150 m

g) The total depth is 4140 m. There are two parts to the trip, the first 150 m covered while accelerating and the second (3990m) covered while moving at constant speed. The parts must be calculated separately. Part one, during acceleration, was already given as taking 30 second. The second part at a constant speed can simply be found using $\bar{v} = d/t$, 10 = 3990 / t, t_2 =399 seconds. So the total time of travel was 429 seconds.

B2004B2.

a) The descent occurs at two different accelerations and must be analyzed in the two sections.
Section 1 starts from rest and accelerates, find the time in that part
$v_{1f} = v_{1i} + a_1t_1$ $2 = 0 + 0.10\ t$ $t_1 = 20$ seconds.

$d_1 = v_{1i}t + ½\ a_1t_1^2$ $d_1 = ½\ (0.10)(20)^2$ $d_1 = 20$ m

Section 2 occurs at a constant speed equal to the final speed in section 1 and will occur over the remaining distance d_2 = 60m.
$\bar{v}_2 = d_2 / t_2$ $2 = 60 / t_2$ $t_2 = 30$ seconds $t_{total} = t_1 + t_2 = 50$ seconds

b) Weight of water above the bell is a cylindrical column with a height of h=80 m and area of A=9 m^2. This gives us the volume of the water above the bell given by V = Ah = 720 m^3.
The weight of this column = $m_{h20}\ g = (\rho_{h20}V)\ g = (1025)(720)(9.8) = 7.2\text{x}10^5$ N

c) $P_{abs} = P_o + \rho gh = 1.01\text{x}10^5 + (1025)(9.8)(80) = 9\text{x}10^5$ Pa

d) Since there is air pressure inside the bell, and the absolute pressure on the outside also includes the air pressure, these two pressures essentially cancel each other out and we only need to push against the water pressure alone so we should use the gauge pressure to find the needed force.
$P_{abs} = P_o + P_{gauge}$ $9\text{x}10^5 = 1.01\text{x}10^5 + P_{gauge}$ $P_{gauge} = 8\text{x}10^5$ Pa.
$F = PA = (8\text{x}10^5)(\pi(0.25)^2) = 1.58\text{x}10^5$ N

e) To reduce the pushing force needed, you could increase the pressure inside the bell to create a smaller pressure difference between inside and outside. Or, by making the area of the hatch smaller the pushing force would be less. Or, you could use a lever inside that uses torque to provide mechanical advantage to amplify an applied force to one side of the lever. This would makes the force pushing the hatch open the same but the required pushing force of a person less.

2005B5.

a) We are given the volume of the raft and the surface area as well. Use this to first find the total height of the raft h_t

$V = Ah_t$ $\quad 1.8 = 8.2\, h_t \quad h_t = 0.22$ m

Since the raft is floating, the weight of the raft must equal the weight of the displaced fluid. We will define "h_s" as being the portion of the height of the raft below the water so that the displaced volume is given by $V=Ah_s$

$m_{raft}g = \rho_{h20}\, V_{disp}\, g$

$\rho_{raft}V_{raft}\, g = \rho_{h20}\, V_{disp}\, g \qquad \rho_{raft}V_{raft} = \rho_{h20}\,(Ah_s) \qquad (650)(1.8) = (1000)(8.2)h_s \qquad h_s = 0.143$ m

$h = h_t - h_s = 0.22 - 0.143 = 0.077$ m (the visible portion of the raft)

b) F_B equals weight of displaced water $= \rho_{h20}\, V_{disp}\, g = \rho_{h20}\,(Ah_s)\, g = (1000)(8.2)(0.143)(9.8) = 11500$ N directed ↑

c) Determine the extra buoyant force that will come from submerging the exposed raft volume $V_{exp} = Ah$

$F_{b(extra)} = \rho_{h20}\, V_{disp}\, g = \rho_{h20}\,(Ah)\, g = (1000)(8.2)(0.077)(9.8) = 6187.7$ N

1 persons weight = mg = 735 N. Total weight allowed / person weight = 6187.7 / 735 = 8.41

So, an extra 8 people could come on without submerging the raft. You could also chop some arms or legs off and throw them on there also until you get up to the extra 0.41 of a person limit.

B2005B5.

a) The force on the plug from the water inherently includes the atmosphere above it, so we use the absolute pressure.

$P_{abs} = P_o + \rho gh = 1.01\text{x}10^5 + (1025)(9.8)(20\text{m}) = 3\text{x}10^5$ Pa

The force is then found with $P = F/A \qquad 3\text{x}10^5 = F / (4\text{x}10^{-5}) \rightarrow F = 12$ N

Note: This calculation of pressure (ρgh) only works since the fluid is at rest (static). For moving fluids, only Bernoulli's equation (or F/A in rare cases) can be applied for determining pressures.

b) Though many of you may know the Torricelli theorem shortcut to this problem, when the AP exam graded this question, simply stating that equation and plugging in lost points. To be safe you should always start with Bernoulli's equation in its full form, cancel out terms that don't exist or are assumed zero, and solve from there.

$P_1 + \rho gy_1 + ½\, \rho v_1^2 = P_2 + \rho gy_2 + ½\, \rho v_2^2$

P_1 and P_2 are both open to atmosphere so are at P_o and cancel. Tank is large so v_1 is assumed small enough to be 0, y_2 is set as zero height.

$\rho gy_1 = ½\, \rho v_2^2 \qquad v_2 = \sqrt{2gy_1}$ (as expected from Torricelli) … $v_2 = \sqrt{2(9.8)(20)} = 19.8$ m/s

c) Volume flow rate $= Q = Av = (4\text{x}10^{-5})(19.8) = 7.92\text{x}10^{-4}\ \text{m}^3/\text{s}$

2007B4.

a) Volume flow rate $= Q = V/t = 7.2\text{x}10^{-4}$ / (2min * 60 sec/min) $= 6\text{x}10^{-6}\ \text{m}^3/\text{s}$

b) Your first thought is probably Bernoulli, but there are too many unknowns so this does not work. We can use the volume flow rate above the find the velocity.

$Q = Av \qquad 6\text{x}10^{-6} = (2.5\text{x}10^{-6})\, v \qquad v = 2.4$ m/s

c) Use Bernoulli, same derivation as in the problem above (B2005B5) … $v_2 = \sqrt{2gh} \qquad (2.4) = \sqrt{2(9.8)h} \qquad h=0.29$m

d) Left of beaker. Based on the formula derived above, the exit velocity is dependent on the height and with less horizontal exit velocity the range will be less ($d_x = v_xt$). This makes sense because less height would result in less pressure and decrease the speed the fluid is ejected at, thus lessening the range.

B2007B4.

a) Use Bernoulli, same derivation as problem B2005B5 … $v_2 = \sqrt{2gh}$ … $v_2 = \sqrt{2(9.8)(0.7)}$… $v_2 = 3.7$ m/s

b) Volume flow rate $Q = Av = \pi(0.001)^2(3.7) = 1.16\text{x}10^{-5}$ m^3/s

c) $Q = V / t$ $\quad 1.16\text{x}10^{-5} = V / (2\text{min} * 60 \text{ s/min})$ $\quad V = 0.0014$ m^3

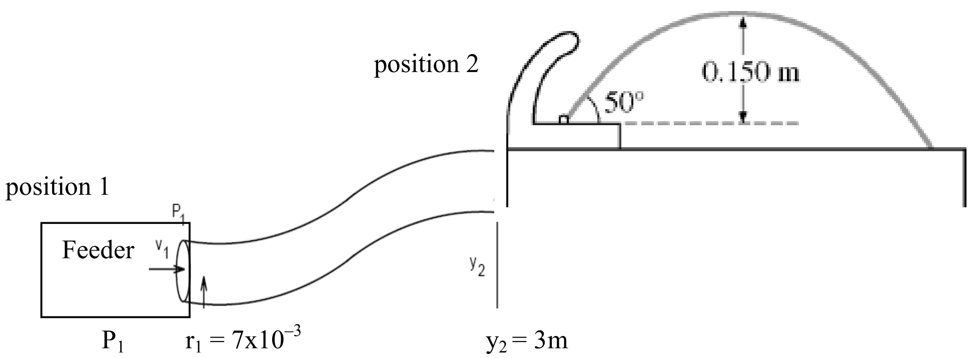
d) Free fall. $\quad d = v_i t + \frac{1}{2} gt^2 \quad -0.25 = (-3.7\ t) + \frac{1}{2}(-9.8)\ t^2$ $\quad$ solve quadratic $\quad t = 0.062$ s
Alternatively, first determine v_f at the 0.25 m location then use $v_f = v_i + at$ to solve for t.

2008B4.

a) Using projectile methods. $\quad v_{fy}^2 = v_{iy}^2 + 2ad_y \quad 0 = (v_i \sin 50)^2 + 2(-9.8)(0.15) \quad v_i = 2.24$ m/s

b) Volume flow rate = $Q = Av = \pi(4\text{x}10^{-3})^2\ (2.24) = 1.13\text{x}10^{-4}$ m^3/s

c) If you don't understand the wording, here is what the problem is saying



First we need to find the velocity of the water at the feeder using continuity
$A_1 v_1 = Q_2 \quad \pi(7\text{x}10^{-3})^2(v_1) = 1.13\text{x}10^{-4} \quad v_1 = 0.73$ m/s

Bernoulli. Position 2 is the fountain spigot which is open so at atmospheric pressure. $y_1=0$ no height.

$P_1 + \rho g y_1 + \frac{1}{2} \rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2} \rho v_2^2$

$P_1 + 0 + \frac{1}{2} (1000)(0.73)^2 = (1.01\text{x}10^5) + (1000)(9.8)(3\text{m}) + \frac{1}{2} (1000)(2.24)^2$

$P_1 = 1.32\text{x}10^5$ Pa which is the absolute pressure of the feeder.

To find the gauge pressure of the feeder. $P_{abs} = P_{gauge} + P_o \quad 1.32\text{x}10^5 = P_{gauge} + 1.01\text{x}10^5$

$P_{gauge} = 31600$ Pa.

Note: This gauge pressure could be determined directly in Bernoulli's equation by realizing that P_1 includes atmospheric pressure as part of its total value and that P_2 was equal to atmospheric pressure, so by elimination of the term P_2, P_1 becomes the gauge pressure. This should be stated in the solution if it is the chosen solution method.

B2008B4

a) Volume flow rate = $Q = Av = \pi(0.015)^2\,(6) = 0.0042\ m^3/s$

b) First we need to find the velocity of the water in the pipe below using continuity
$A_1v_1 = Q_2$ $\qquad \pi(0.025)^2(v_1) = 0.0042$ $\qquad v_1 = 2.16\ m/s$

Bernoulli. Position 2 is the fountain spigot which is open so at atmospheric pressure. y_1=0 no height.
$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$
$P_1 + 0 + \frac{1}{2}(1000)(2.16)^2 = (1.01\text{x}10^5) + (1000)(9.8)(2.5m) + \frac{1}{2}(1000)(6)^2$ $\qquad P_1 = 141000\ Pa$

c) Determine the launch speed needed to reach 4m.
Free fall of a water droplet. $\qquad v_f^2 = v_i^2 + 2gd$ $\qquad (0) = v_i^2 + 2(-9.8)(4)$ $\qquad v_i = 8.85\ m/s$

Use flow rate to find new area needed. $Q = Av$ $\qquad (0.0042) = A\,(8.85)$ $\qquad A_{new} = 4.75\text{x}10^{-4}\ m^3$

Find new radius $\quad A_{new} = \pi\, r_{new}^2$ $\qquad 4.75\text{x}10^{-4}\ m^3 = \pi\, r_{new}^2$ $\qquad r_{new} = 0.0122\ m$

2009B5.

a) There are three forces acting on the masses in each case. Tension up, buoyant force up, weight down. Since they are at rest we have. $F_{net} = 0$ $\quad F_t + F_b = mg$ $\quad F_t = mg - F_b$ $\quad$ so the largest F_b makes the largest F_t

We are to assume the diagram is to scale and that clearly the volumes of the three containers are different. The one with the largest volume displaces the largest amount and weight of water and will have the largest buoyant force acting on it. So since they all displace different volumes (and weights) of water they all have different buoyant forces, and based on the equation shown above will have different tensions.

b) The mass of the object is given by $m = \rho_{obj}V_{obj.}$
Using the equation from part a,
$F_t + F_b = mg,$ $\qquad F_t + F_b = (\rho_{obj}V_{obj.})\,g$ $\qquad (0.0098) + F_b = (1300)(1\text{x}10^{-5})(9.8)$ $\qquad F_b = 0.1176\ N$

c) The buoyant force is by definition equal to the weight of the displaced fluid.
$F_b = (\rho_{fluid}V_{disp.})\,g$ $\qquad 0.1176 = \rho_{fluid}\,(1\text{x}10^{-5})(9.8)$ $\qquad \rho_{fluid} = 1200\ kg/m^3$

d) With only half of the volume submerged, ½ as much water will be displaced and the buoyant force will be half the size. Based on the formula from part A, less buoyant from will make a larger tension. This also makes sense conceptually. Objects have large apparent weights in air than water so having some of it in the air will increase its apparent weight.

B2009B3.

a) Using fluid continuity. $A_1v_1 = A_2v_2$ $(1x10^{-4})(v_1) = (0.5x10^{-4})(8.2)$ $v_a = 4.1$ m/s

b) Bernoulli. Position B is the fountain spigot which is open so at atmospheric pressure. y_1=0 no height.

$P_1 + \rho g y_1 + ½ \rho v_1^2 = P_2 + \rho g y_2 + ½ \rho v_2^2$

$P_1 + 0 + ½ (1000)(4.1)^2 = (1.01x10^5) + (1000)(9.8)(0.5m) + ½ (1000)(8.2)^2$ $P_1 = 1.3x10^5$ Pa

c) Free fall of a water droplet. $v_f^2 = v_i^2 + 2gd$ $(0)^2 = (8.2)^2 + 2(-9.8)(d)$ d = 3.43m

d) Projectile method, in y direction.

$d_y = v_{iy}t + ½ gt^2$ $d_y = (v_i \sin \theta) t + ½ gt^2$ $0 = (8.2 \sin 60)t + ½ (-9.8)t^2$ t = 1.45 sec

X direction. $d_x = v_x t$ $d_x = (v_i \cos \theta) t$ $d_x = (8.2 \cos 60)(1.45)$ $d_x = 5.95$ m

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SUP1.

a) $\rho = m/V$ = 12 / (0.5x0.2x0.2) = 600 kg / m^3

b) The block will float based on its density. For floating, block weight = buoyant force.

$m_{obj}g = p_{h20} V_{disp} g$ $m_{obj} = p_{h20} A_{sqaure}(h_{submerged})$ $12 = 1000(0.2x0.2)h_{sub}$ $h_{sub} = 0.3$ m

c) The extra weight added should equal the extra buoyant force created by submerging the remaining 0.2 m of height.

$F_{b(extra)} = p_{h20} V_{disp} g = (1000)(0.2x0.2x0.2)(9.8) = 78.4$ N 78.4 / 9.8 = 8kg of extra mass.

SUP2.

a) Using fluid continuity. $A_1v_1 = A_2v_2$ $(4)(10) = (2)(v_2)$ $v_2 = 20$ m/s

b) Bernoulli. $\rho g y_1$ terms cancel out since the pipe stays on the same level.

$P_1 + \rho g y_1 + ½ \rho v_1^2 = P_2 + \rho g y_2 + ½ \rho v_2^2$

$2x10^5 + 0 + ½ (1000)(10)^2 = P_2 + 0 + ½ (1000)(20)^2$ $P_2 = 50000$ Pa.

Since P_1 was the gauge pressure and did not include P_o, P_2 will also come out as the gauge pressure.

SUP3.

a) Bernoulli. $\rho g y_1$ terms cancel out since the height difference is negligible.

$P_1 + \rho g y_1 + ½ \rho v_1^2 = P_2 + \rho g y_2 + ½ \rho v_2^2$ … rearrange equation so we can find $P_2 - P_1$ which is the ΔP

$P_2 - P_1 = ½ \rho v_1^2 - ½ \rho v_2^2$ $\Delta P = ½ (1.2) (50^2 - 40^2) = 540$ Pa

b) i) $\Delta P = F_{lift} / A$ $540 = F_{lift}$ / (9x2 wings) $F_{lift} = 9720$ N

ii) $F_{net} = 0$ $F_{lift} = mg$ $9720 = m (9.8)$ m = 992 kg.

SUP4.

This problem involves floating objects, so weight of object = buoyant force $m_{obj}\, g = \rho_{fluid}\, V_{disp}\, g$

In general … $m_{obj} = \rho_{obj} V_{obj}$

Giving … $\rho_{obj} V_{obj}\, g = \rho_{fluid}\, V_{disp}\, g$ … $\rho_{obj} V_{obj} = \rho_{fluid}\, V_{disp}$

Water	Oil
$\rho_{obj} V_{obj} = \rho_{fluid}\, V_{disp}$	$\rho_{obj} V_{obj} = \rho_{fluid}\, V_{disp}$
$\rho_w V = (1000)(2/3\ V)$	$(666.67)V = \rho_{oil}\,(9/10\ V)$
$\rho_w = 666.67\ kg / m^3$	$\rho_{oil} = 740.74\ kg / m^3$

SUP5.

a) $P_{abs} = P_{gauge} + P_o$ $P_{abs} = \rho gh + 1.01x10^5$ $P_{abs} = (1000)(9.8)(16) + 1.01x10^5 =$ 260000 Pa

b) Use Bernoulli, same derivation as problem B2005B5 … $v_2 = \sqrt{2gh}$ … $v_2 = \sqrt{2(9.8)(11)}$… $v_2 = 14.7$ m/s

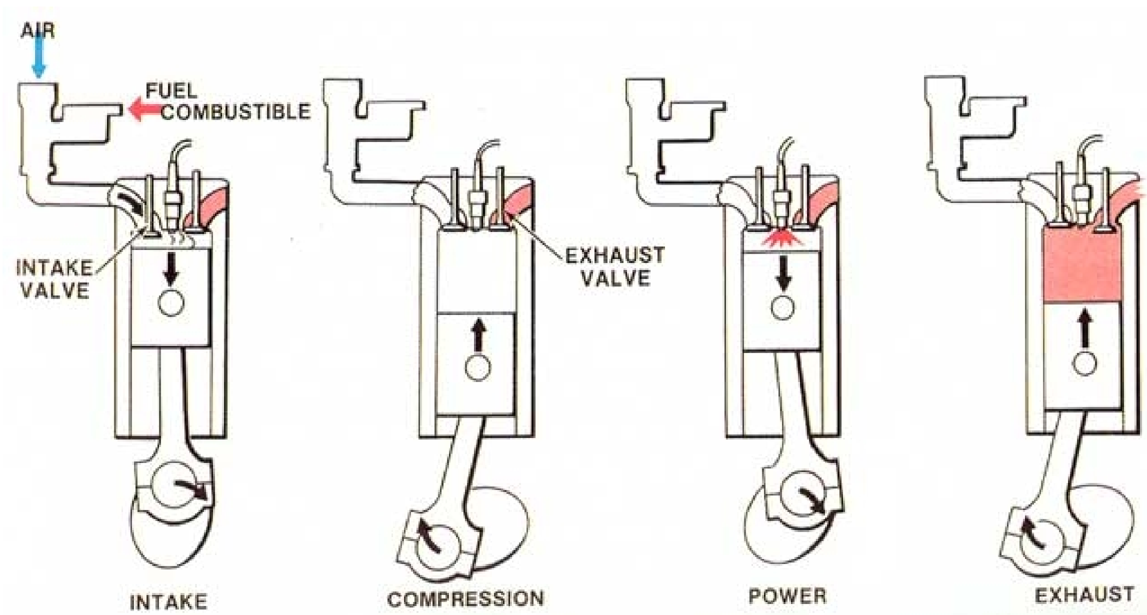
c) Using projectile methods. $d_y = v_{iy}t + ½\, at^2$ $-3 = 0 + ½\,(-9.8)\, t^2$ $t = 0.78$ sec

$d_x = v_x t = (14.7)\,(0.78) = 11.5$ m

d) An increase in atmospheric pressure around the damn increases both P_1 and P_2 equally so there is no net effect on these terms in Bernoulli's equation, which means the exit velocity would be the same.

Chapter 16

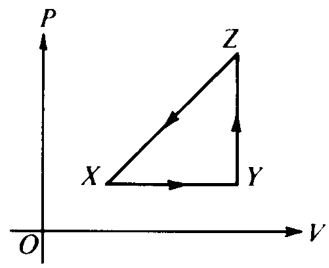
Thermodynamics



AP Physics Multiple Choice Practice – Thermodynamics

1. An ideal gas is made up of N diatomic molecules, each of mass M. All of the following statements about this gas are true EXCEPT:
(A) The temperature of the gas is proportional to the average translational kinetic energy of the molecules.
(B) All of the molecules have the same speed.
(C) The molecules make elastic collisions with each other and with the walls of the container.
(D) The average number of collisions per unit time that the molecules make with the walls of the container depends on the temperature of the gas.

Questions 2-3



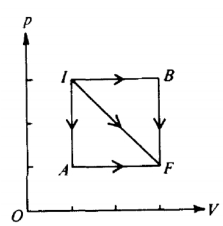
A thermodynamic system is taken from an initial state X along the path XYZX as shown in the PV-diagram.

2. For the process X→Y, ΔU is greater than zero and
(A) Q < 0 and W = 0 (B) Q < 0 and W > 0 (C) Q > 0 and W < 0 (D) Q > 0 and W > 0

3. For the process Y→Z, Q is greater than zero and
(A) W < 0 & ΔU = 0 (B) W = 0 & ΔU < 0 (C) W = 0 & ΔU > 0 (D) W > 0 & ΔU > 0

4. An ideal gas confined in a box initially has pressure p. If the absolute temperature of the gas is doubled and the volume of the box is quadrupled, the pressure is
(A) p/8 (B) p/4 (C) p/2 (D) 2p

5. An ideal gas in a closed container initially has volume V, pressure P. and Kelvin temperature T. If the temperature is changed to 3T, which of the following pairs of pressure and volume values is possible?
(A) 3P and V (B) 3P and 3V (C) P and V/3 (D) P/3 and V

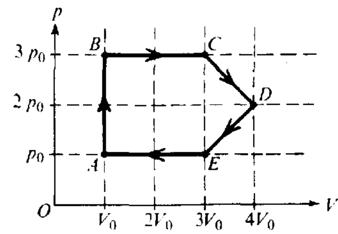


6. If three identical samples of an ideal gas are taken from initial state I to final state F along the paths IAF, IF, and IBF as shown in the pV-diagram above, which of the following must be true?
(A) The heat absorbed by the gas is the same for all three paths.
(B) The change in internal energy of the gas is the same for all three paths.
(C) The expansion along path IF is adiabatic.
(D) The expansion along path IF is isothermal.

7. If the average kinetic energy of the molecules in an ideal gas at a temperature of 300 K is E, the average kinetic energy at a temperature of 600 K is
(A) E (B) $\sqrt{2}E$ (C) $2E$ (D) $4E$

8. A metal rod of length L and cross-sectional area A connects two thermal reservoirs of temperatures T_1 and T_2. The amount of heat transferred through the rod per unit time is directly proportional to
(A) A and L (B) A and 1/L (C) 1/A and L (D) 1/A and 1/L

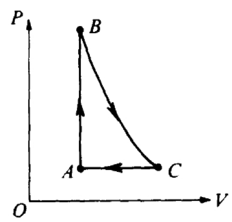
Questions 9-10



An ideal gas undergoes a cyclic process as shown on the graph above of pressure p versus volume V.

9. During which process is no work done on or by the gas?
(A) AB (B) BC (C) CD (D) EA

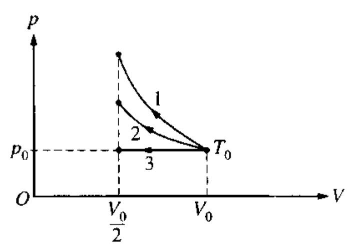
10. At which point is the gas at its highest temperature?
(A) A (B) B (C) C (D) D



11. Gas in a chamber passes through the cycle ABCA as shown in the diagram above. In the process AB, 12 joules of heat is transferred to the gas. In the process BC, no heat is exchanged with the gas. For the complete cycle ABCA, the work done by the gas is 8 joules. How much heat is added to or removed from the gas during process CA?
(A) 20 J is removed. (B) 4 J is removed. (C) 4 J is added. (D) 20 J is added.

12. If the gas in a container absorbs 275 joules of heat, has 125 joules of work done on it, and then does 50 joules of work, what is the increase in the internal energy of the gas?
(A) 450 J (B) 400 J (C) 350 J (D) 200 J

Questions 13-14

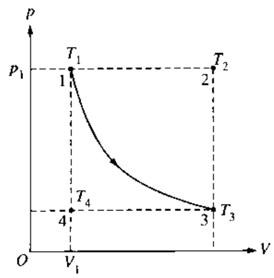


A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

13. Which of the following is true of the mechanical work done on the gas?
(A) It is greatest for process 1.
(B) It is greatest for process 2.
(C) It is greatest for process 3.
(D) It is the same for all three processes.

14. Which of the following is true of the final temperature of this gas?
(A) It is greatest for process 1. (B) It is greatest for process 2.
(C) It is greatest for process 3. (D) It is the same for all three processes.

15. In a certain process, 400 J of heat is transferred to a system and the system simultaneously does 100 J of work. The change in internal energy of the system is
(A) 500 J (B) 300 J (C) –100 J (D) –300 J



16. **Multiple Correct.** An ideal gas is initially in a state that corresponds to point 1 on the graph above, where it has pressure p_1, volume V_1, and temperature T_1. The gas undergoes an isothermal process represented by the curve shown, which takes it to a final state 3 at temperature T_3. If T_2 and T_4 are the temperatures the gas would have at points 2 and 4, respectively, which of the following relationships is true? Select two answers:
(A) $T_1 < T_3$ (B) $T_1 < T_2$ (C) $T_1 = T_3$ (D) $T_1 = T_4$

17. The absolute temperature of a sample of monatomic ideal gas is doubled at constant volume. What effect, if any, does this have on the pressure and density of the sample of gas?

	Pressure	Density
(A)	Remains the same	Remains the same
(B)	Remains the same	Doubles
(C)	Doubles	Remains the same
(D)	Doubles	Doubles

18. Which of the following statements is NOT a correct assumption of the classical model of an ideal gas?
(A) The molecules are in random motion.
(B) The volume of the molecules is negligible compared with the volume occupied by the gas.
(C) The molecules obey Newton's laws of motion.
(D) The collisions between molecules are inelastic.

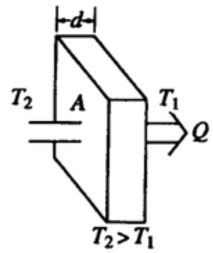
19. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If v_1 is the average speed of the gas molecules before the absorption of heat and v_2 is their average speed after the absorption of heat, what is the ratio v_2/v_1?
(A) 4 (B) 2 (C) $\sqrt{2}$ (D) 1/2

20. Two blocks of steel, the first of mass 1 kg and the second of mass 2 kg, are in thermal equilibrium with a third block of aluminum of mass 2 kg that has a temperature of 400 K. What are the respective temperatures of the first and second steel blocks?
(A) 400 K and 200 K (B) 200 K and 400 K (C) 400 K and 400 K (D) 800 K and 400 K

21. An ideal gas may be taken from one state to another state with a different pressure, volume, and temperature along several different paths. Quantities that will always be the same for this process, regardless of which path is taken, include which of the following?
I. The change in internal energy of the gas
II. The heat exchanged between the gas and its surroundings
III. The work done by the gas
(A) I only (B) II only (C) I and III only (D) II and III only

22. A square steel plate with sides of length 1.00 m has a hole in its center 0.100 m in diameter. If the entire plate is heated to such a temperature that its sides become 1.01 m long, the diameter of the hole will be
(A) 0.090 m (B) 0.099 m (C) 0.101 m (D) 0.110 m

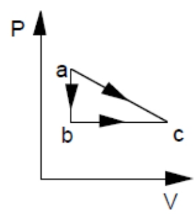
23. Which of the following will occur if the average speed of the gas molecules in a closed rigid container is increased?
(A) The density of the gas will decrease. (B) The density of the gas will increase.
(C) The pressure of the gas will increase. (D) The pressure of the gas will decrease.



24. In time *t*, an amount of heat *Q* flows through the solid door of area *A* and thickness *d* represented above. The temperatures on each side of the door are T_2 and T_1, respectively. Which of the following changes would be certain to decrease *Q*?
(A) Increasing *A* only (B) Decreasing *d* only
(C) Increasing *d* and $T_2 - T_1$ only (D) Decreasing *A* and $T_2 - T_1$ only

25. A gas with a fixed number of molecules does 32 J of work on its surroundings, and 16 J of heat are transferred from the gas to the surroundings. What happens to the internal energy of the gas?
(A) It decreases by 48 J. (B) It decreases by 16 J. (C) It increases by 16 J. (D) It increases by 48 J.

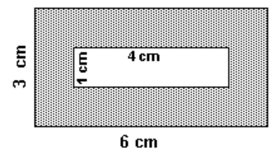
26. A mass *m* of helium gas is in a container of constant volume *V*. It is initially at pressure *p* and absolute (Kelvin) temperature *T*. Additional helium is added, bringing the total mass of helium gas to *3m*. After this addition, the temperature is found to be *2T*. What is the gas pressure?
(A) 2/3 *p* (B) 3/2 *p* (C) 3 *p* (D) 6 *p*



27. A gas can be taken from state *a* to *c* by two different reversible processes, *a*⇨*c* or *a*⇨*b*⇨*c*. During the direct process *a*⇨*c*, 20.0 J of work are done by the system and 30.0 J of heat are added to the system. During the process *a*⇨*b*⇨*c*, 25.0 J of heat are added to the system. How much work is done by the system during *a*⇨*b*⇨*c*?
(A) 5.0 J (B) 10.0 J (C) 15.0 J (D) 20.0 J

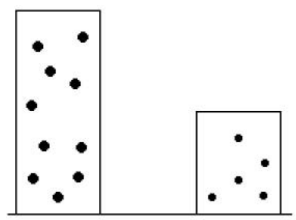
28. When an ideal gas is isothermally compressed:
(A) thermal energy flows from the gas to the surroundings.
(B) thermal energy flows from the surroundings to the gas.
(C) no thermal energy enters or leaves the gas.
(D) the temperature of the gas increases.

30. A 200 gram sample of copper is submerged in 100 grams of water until both the copper and water are at the same temperature. Which of the following statements would be true?
(A) the molecules of the water and copper would have equal average speeds
(B) the molecules of the water and copper would have equal average momenta
(C) the molecules of the water and copper would have equal average kinetic energies
(D) the water molecules would have twice the average speed of the copper molecules



31. A rectangular piece of metal 3 cm high by 6 cm wide has a hole cut in its center 1cm high by 4 cm wide as shown in the diagram at right. As the metal is warmed from 0^oC to 100^0C, what will happen to the dimensions of the hole?
    (A) both height and width will increase
    (B) both height and width will decrease
    (C) height will increase while width will decrease
    (D) height will decrease while width will increase

32. A gas is enclosed in a cylindrical piston. When the gas is heated from 0ºC to 100ºC, the piston is allowed to move to maintain a constant pressure. According to the Kinetic-Molecular Theory of Matter
    (A) the molecules continue to strike the sides of the container with the same energy
    (B) the number of molecules of gas must increase
    (C) the size of the individual molecules has increased
    (D) the average speed of the molecules has increased



33. Two containers are filled with gases at the same temperature. In the container on the left is a gas of molar mass *2M,* volume *2V,* and number of moles *2n.* In the container on the right is a gas of molar mass *M,* volume *V,* and moles *n*. Which is most nearly the ratio of the pressure of the gas on the left to the pressure of the gas on the right?
    (A) 1:1 (B) 2:1 (C) 4:1 (D) 8:1

34. A fan blows the air and gives it kinetic energy. An hour after the fan has been turned off, what has happened to the kinetic energy of the air?
    (A) it turns into thermal energy (B) it turns into sound energy
    (C) it turns into potential energy (D) it turns into electrical energy

35. According to the kinetic theory of gases, when the absolute temperature of an ideal gas doubles, the average kinetic energy of the molecules of the gas
    (A) quadruples (B) doubles (C) is cut in half (D) is quartered

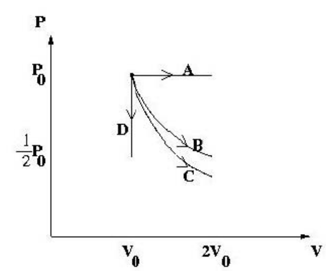
36. When gas escapes from a pressurized cylinder, the stream of gas feels cool. This is because
    (A) work is being done at the expense of thermal energy
    (B) of the convection inside the cylinder
    (C) pressurized cylinders are good thermal insulators
    (D) the moisture in the air condenses and cools

37. Two completely identical samples of the same ideal gas are in equal volume containers with the same pressure and temperature in containers labeled A and B. The gas in container A performs non-zero work W on the surroundings during an isobaric (constant pressure) process before the pressure is reduced isochorically (constant volume) to ½ its initial amount. The gas in container B has its pressure reduced isochorically (constant volume) to ½ its initial value and then the gas performs non-zero work W on the surroundings during an isobaric (constant pressure) process.

After the processes are performed on the gases in containers A and B, which is at the higher temperature?
(A) The gas in container A
(B) The gas in container B
(C) The value of the work W is necessary to answer this question.
(D) The value of the work W is necessary, along with both the initial pressure and volume, in order to answer the question.

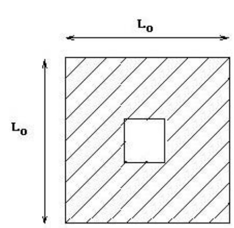
38. The volume of an ideal gas changes as the gas undergoes an isobaric (constant pressure) process starting from temperature 273 ^{O}C and ending at 546^{O}C. What is the ratio of the new volume of the gas to the old volume (V_{new}/V_{old})?
(A) $\frac{1}{2}$ (B) $\frac{2}{3}$ (C) $\frac{3}{2}$ (D) 2

39. A frozen hamburger in plastic needs to be thawed quickly. Which of the methods described provides the most rapid thawing of the burger?
(A) Place the burger itself in a metal pan at room temperature.
(B) Place the burger itself on the ceramic kitchen counter at room temperature.
(C) Place the burger in its package on the kitchen counter at room temperature.
(D) Place the burger in its package in a pot of non-boiling warm water.



40. **Multiple Correct.** The PV diagram shows four different possible reversible processes performed on a monatomic ideal gas. Process A is isobaric (constant pressure). Process B is isothermal (constant temperature). Process C is adiabatic. Process D is isochoric (constant volume). For which processes does the temperature of the gas decrease? Select two answers:
(A) Process A (B) Process B (C) Process C (D) Process D

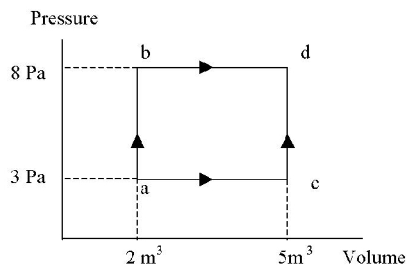
41. A pure 4-mole sample of a newly discovered monatomic ideal gas is sitting in a container at equilibrium in a 20.0ºC environment. According to the kinetic theory of gases, what is the average kinetic energy per molecule for this gas?
(A) 4.14×10^{-22} J (B) 2.02×10^{-21}J (C) 6.07×10^{-21} J
(D) The molar mass of the gas is needed to answer this question.



42. A uniform square piece of metal has initial side length L_0 . A square piece is cut out of the center of the metal. The temperature of the metal is now raised so that the side lengths are increased by 4%. What has happened to the area of the square piece cut out of the center of the metal?
(A) It is increased by 8 % (B) It is increased by 4 % (C) It is decreased by 4 % (D) It is decreased by 8 %

43. A monatomic ideal gas at pressure $P = 10^5$ Pa is in a container of volume $V = 12$ m^3 while at temperature $T =$ 50ºC. How many molecules of gas are in the container?
(A) 1.74×10^{27} (B) 2.69×10^{26} (C) 2888 (D) 447

44. Absolute zero is best described as that temperature at which
(A) water freezes at standard pressure.
(B) the molecules of a substance have a maximum kinetic energy.
(C) the molecules of a substance have a maximum potential energy.
(D) the molecules of a substance have minimum kinetic energy.



45. In the Pressure versus Volume graph shown, in the process of going from a to b 60 J of heat are added, and in the process of going from b to d 20 J of heat are added. In the process of going a to c to d, what is the total heat added?
(A) 80 J (B) 65 J (C) 56 J (D) 47 J

46. Which is not true of an isochoric process on an enclosed ideal gas in which the pressure decreases?
(A) The work done is zero. (B) The internal energy and temperature of the gas decreases.
(C) The heat is zero. (D) The rms speed of the gas molecules decreases.

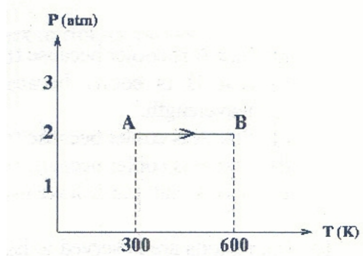
47. One mole of an ideal gas has a temperature of 100°C. If this gas fills the 10.0m^3 volume of a closed container, what is the pressure of the gas?
(A) 0.821 Pa (B) 3.06 Pa (C) 83.1 Pa (D) 310 Pa

48. An ideal gas is enclosed in a container. The volume of the container is reduced to half the original volume at constant temperature. According to kinetic theory, what is the best explanation for the increase in pressure created by the gas?
(A) The average speed of the gas particles decreases, but they hit the container walls more frequently.
(B) The average speed of the gas particles is unchanged, but they hit the container walls more frequently.
(C) The average speed of the gas particles increases as does the frequency with which they hit the container walls.
(D) The average speed of the gas particles increases, overcoming the decreased frequency that they hit the container walls.

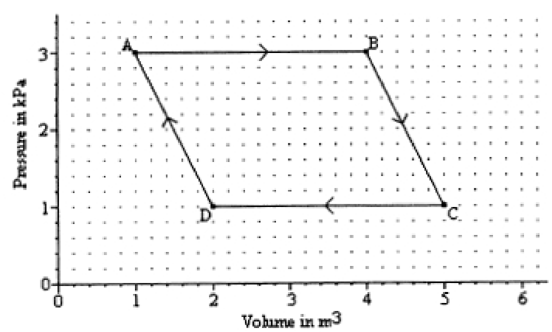
49. A mole of a monatomic ideal gas has pressure *P*, volume *V*, and temperature *T*. Which of the following processes would result in the greatest amount of energy added to the gas from heat?
(A) A process doubling the temperature at constant pressure.
(B) An adiabatic expansion doubling the volume.
(C) A process doubling the pressure at constant volume.
(D) A process doubling the volume at constant temperature.

50. An ideal gas in a closed container of volume 6.0 *L* is at a temperature of 100ºC. If the pressure of the gas is 2.5 atm, how many moles of gas are in the container?
(A) 0.0048 (B) 0.018 (C) 0.49 (D) 1.83

51. An ideal gas undergoes an isobaric expansion followed by an isochoric cooling. Which of the following statements *must* be true after the completion of these processes?
(A) The final pressure is less than the original pressure.
(B) The final volume is less than the original volume.
(C) The final temperature is less than the original temperature.
(D) The total quantity of heat, Q, associated with these processes is positive.



52. Two moles of a monatomic ideal gas undergoes the process from A to B, shown in the diagram above by the solid line. Using the sign convention that work is positive when surroundings do work on the system, how much work is done in the process AB?
(A) 5000 J (B) 1200 J (C) –1200 J (D) –5000 J



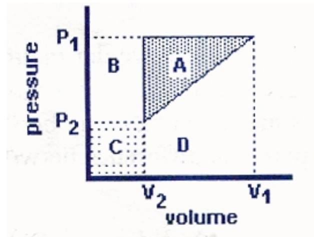
53. A sample of gas is caused to go through the cycle shown in the pV diagram shown above. What is the net work done by the gas during the cycle?
(A) 4,000 J (B) 6,000 J (C) 8,000 J (D) 12,000 J

54. A sample of an ideal monatomic gas is confined in a rigid 0.008 m^3 container. If 40 joules of heat energy were added to the sample, how much would the pressure increase?
(A) 320 Pa (B) 1,600 Pa (C) 3,333 Pa (D) 5,000 Pa

55. Hydrogen gas (H_2) and oxygen gas (O_2) are in thermal equilibrium. How does the average speed of the hydrogen molecules compare to the average speed of oxygen molecules?
(A) equal (B) 4 times greater (C) 8 times greater (D) 16 times greater

56. Hydrogen gas is contained in a rigid container. A second rigid container of equal volume contains oxygen gas. If the average rms velocities of the molecules in each container is the same, which of the following *must* be true?
(A) The oxygen gas would apply the greater pressure.
(B) The temperature of both gasses would be identical.
(C) There would be an equal pressure in each container.
(D) The oxygen gas would have the higher temperature.

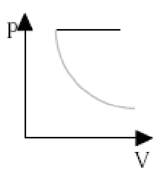
57. A mole of ideal gas at STP is heated in an insulated constant volume container until the average velocity of its molecules doubled. Its pressure would therefore increase by what factor?
(A) 0.5 (B) 1 (C) 2 (D) 4

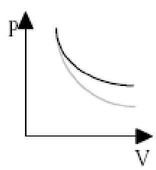


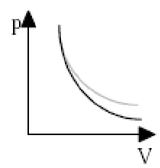
58. **Multiple Correct.** A sample of gas was first compressed from V_1 to V_2 at a constant pressure of P_1. The sample was then cooled so that the pressure went from P_1 to P_2 while the volume remained constant at V_2. Finally the sample was allowed to expand from V_2 back to V_1 while the pressure increased from P_2 back to P_1 as shown in the diagram. Which of the following statements are correct? Select two answers.
   (A) The area A represents the energy that is lost by the gas in this cycle.
   (B) The area A + D represents the "+" work done <u>on</u> the gas during the first compression.
   (C) The area D represents the "+" work done <u>on</u> the gas during the final expansion.
   (D) There was no energy lost or gained by the gas in this cycle.

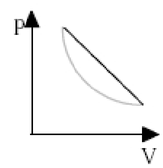
59. **Multiple Correct.** One end of a metal rod of length L and cross-sectional area A is held at a constant temperature T_1. The other end is held at a constant T_2. Which of the statements about the amount of heat transferred through the rod per unit time are true? Select two answers.
   (A) The rate of heat transfer is proportional to A.
   (B) The rate of heat transfer is proportional to $1/(T_1 - T_2)$.
   (C) The rate of heat transfer is proportional to L.
   (D) The rate of heat transfer is proportional to $(T_1 - T_2)$.

60. On all of the pV diagrams shown below the lighter curve represents isothermal process, a process for which the temperature remains constant. Which dark curve best represents an adiabatic process?



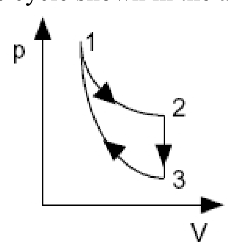
(A)


(B)


(C)


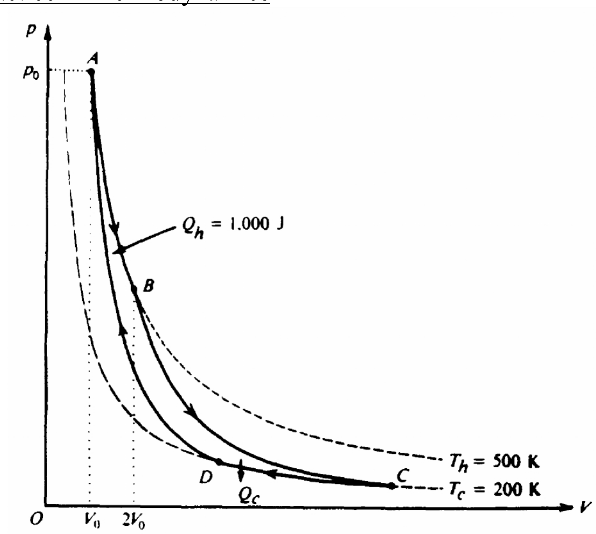
(D)

61. Three processes compose a thermodynamic cycle shown in the accompanying pV diagram of an ideal gas.



Process 1→2 takes place at constant temperature (300 K). During this process 60 J of heat enters the system.
Process 2→3 takes place at constant volume. During this process 40 J of heat leaves the system.
Process 3→1 is adiabatic. T_3 is 275 K.

What is the change in internal energy of the system during process 3→1?
(A) –40 J (B) –20 J (C) +20 J (D) +40 J

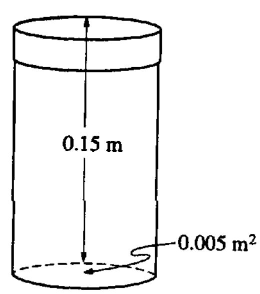


1983B4. The pV-diagram above represents the states of an ideal gas during one cycle of operation of a reversible heat engine. The cycle consists of the following four processes.

Process	**Nature of Process**
AB	Constant temperature (T_h = 500 K)
BC	Adiabatic
CD	Constant temperature (T_c = 200 K)
DA	Adiabatic

During process A B, the volume of the gas increases from V_o to $2V_o$ and the gas absorbs 1,000 joules of heat.

a. The pressure at A is $p_{o.}$ Determine the pressure at B.
b. Using the first law of thermodynamics, determine the work performed on the gas during the process AB.
c. During the process AB, does the entropy of the gas increase, decrease, or remain unchanged? Justify your answer.
d. Calculate the heat Q_c given off by the gas in the process CD.
e. During the full cycle ABCDA is the total work the performed on the gas by its surroundings positive, negative, or zero? Justify your answer.



1996B7 The inside of the cylindrical can shown above has cross-sectional area 0.005 m^2 and length 0.15 m. The can is filled with an ideal gas and covered with a loose cap. The gas is heated to 363 K and some is allowed to escape from the can so that the remaining gas reaches atmospheric pressure (1.0×10^5 Pa). The cap is now tightened, and the gas is cooled to 298 K.

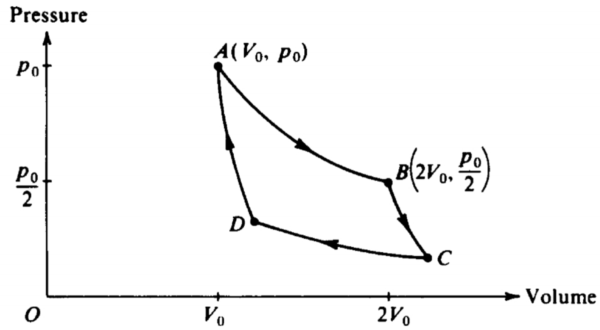
a. What is the pressure of the cooled gas?
b. Determine the upward force exerted on the cap by the cooled gas inside the can.
c. If the cap develops a leak, how many moles of air would enter the can as it reaches a final equilibrium at 298 K and atmospheric pressure? (Assume that air is an ideal gas.)

1986B5 (modified) A proposed ocean power plant will utilize the temperature difference between surface seawater and seawater at a depth of 100 meters. Assume the surface temperature is 25° Celsius and the temperature at the 100-meter depth is 3° Celsius.

a. What is the ideal (Carnot) efficiency of the plant?

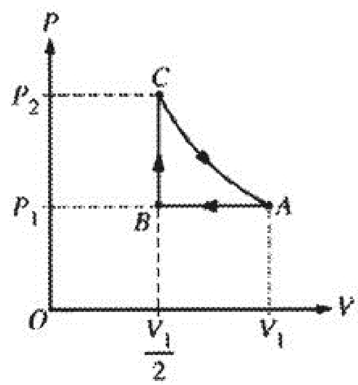
b. If the plant generates useful energy at the rate of 100 megawatts while operating with the efficiency found in part (a), at what rate is heat given off to the surroundings?

The diagram below represents the Carnot cycle for a simple reversible (Carnot) engine in which a fixed amount of gas, originally at pressure p_o and volume V_o follows the path ABCDA.



c. In the chart below, for each part of the cycle indicate with +, -, or 0 whether the heat transferred Q and temperature change ΔT are positive, negative, or zero, respectively. (Q is positive when heat is added to the gas, and ΔT is positive when the temperature of the gas increases.)

	Q	ΔT
AB		
BC		
CD		
DA		



2004Bb5 One mole of an ideal gas is initially at pressure P_1, volume V_1, and temperature T_1, represented by point A on the PV diagram above. The gas is taken around cycle $ABCA$ shown. Process AB is isobaric, process BC is isochoric, and process CA is isothermal.

a. Calculate the temperature T_2 at the end of process AB in terms of temperature T_1.

b. Calculate the pressure P_2 at the end of process BC in terms of pressure P_1.

c. Calculate the net work done on the gas when it is taken from A to B to C. Express your answer in terms of P_1 and V_1.

d. Indicate below all of the processes that result in heat being added to the gas.

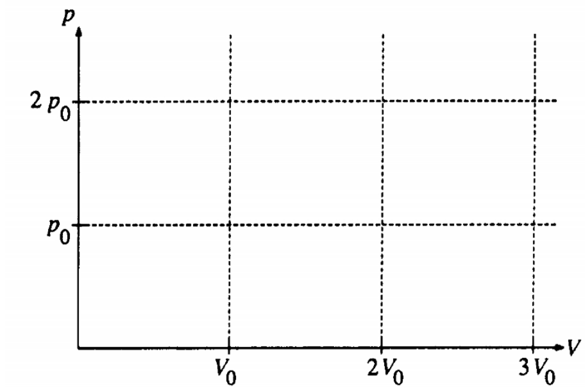
____ *AB* ____ *BC* ____ *CA*

Justify your answer.

1989B4 (modified) An ideal gas initially has pressure p_o, volume V_o, and absolute temperature T_o. It then undergoes the following series of processes:

I. It is heated, at constant volume, until it reaches a pressure $2p_o$.
II. It is heated, at constant pressure, until it reaches a volume $3 V_o$.
III. It is cooled, at constant volume, until it reaches a pressure p_o.
IV. It is cooled, at constant pressure, until it reaches a volume V_o.

a. On the axes below
i. draw the p-V diagram representing the series of processes;
ii. label each end point with the appropriate value of absolute temperature in terms of T_o.

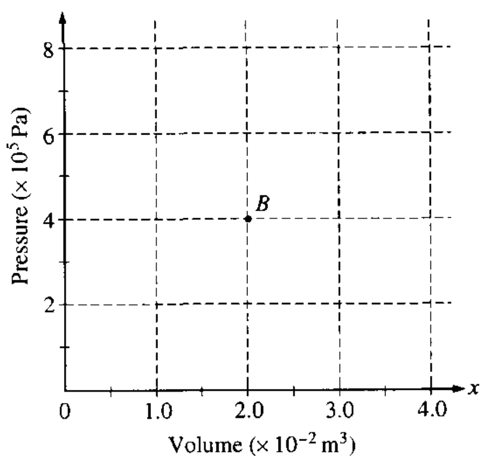


b. For this series of processes, determine the following in terms of p_o and V_o.
i. The net work done on the gas
ii. The net change in internal energy
iii. The net heat absorbed

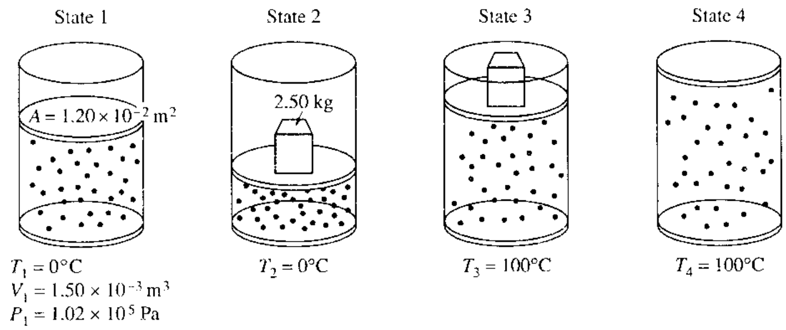
c. Determine the heat transferred during process 2 in terms of p_o and V_o.

1999B7. A cylinder contains 2 moles of an ideal monatomic gas that is initially at state A with a volume of 1.0×10^{-2} m^3 and a pressure of 4.0×10^5 Pa. The gas is brought isobarically to state B. where the volume is 2.0×10^{-2} m^3. The gas is then brought at constant volume to state C, where its temperature is the same as at state A. The gas is then brought isothermally back to state A.

a. Determine the pressure of the gas at state C.
b. On the axes below, state B is represented by the point B. Sketch a graph of the complete cycle. Label points A and C to represent states A and C, respectively.



c. State whether the net work done on the gas during the complete cycle is positive, negative, or zero. Justify your answer.
d. State whether this device is a refrigerator or a heat engine. Justify your answer.



Note: Figures not drawn to scale.

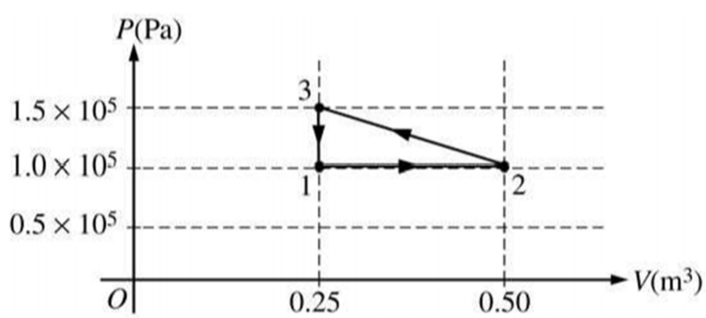
2001B6. A cylinder is fitted with a freely moveable piston of area 1.20×10^{-2} m^2 and negligible mass. The cylinder below the piston is filled with a gas. At state 1, the gas has volume 1.50×10^{-3} m^3, pressure 1.02×10^5 Pa, and the cylinder is in contact with a water bath at a temperature of 0°C. The gas is then taken through the following four-step process.

- A 2.50 kg metal block is placed on top of the piston, compressing the gas to state 2, with the gas still at 0°C.
- The cylinder is then brought in contact with a boiling water bath, raising the gas temperature to 100°C at state 3.
- The metal block is removed and the gas expands to state 4 still at 100°C.
- Finally, the cylinder is again placed in contact with the water bath at 0°C, returning the system to state 1.

a. Determine the pressure of the gas in state 2.
b. Determine the volume of the gas in state 2.
c. Indicate below whether the process from state 2 to state 3 is isothermal, isobaric, or adiabatic.

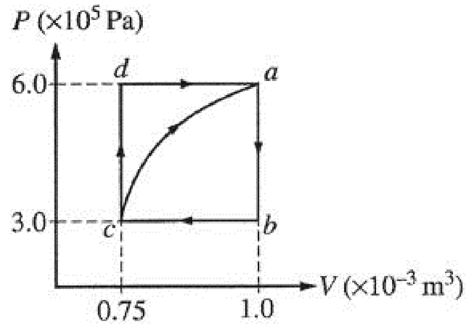
_____Isothermal _____Isobaric _____Adiabatic
Explain your reasoning.

d. Is the process from state 4 to state 1 isobaric? _____Yes _____No
Explain your reasoning.
e. Determine the volume of the gas in state 4.



2006B5 A cylinder with a movable frictionless piston contains an ideal gas that is initially in state 1 at 1×10^5 Pa, 373 K, and 0.25 m^3. The gas is taken through a reversible thermodynamic cycle as shown in the *PV* diagram above.

a. Calculate the temperature of the gas when it is in the following states.
i. State 2
ii. State 3
b. Calculate the net work done on the gas during the cycle.
c. Was heat added to or removed from the gas during the cycle?
Added _____ Removed _____ Neither added nor removed _____
Justify your answer.



2003B5. A cylinder with a movable piston contains 0.1 mole of a monatomic ideal gas. The gas, initially at state *a,* can be taken through either of two cycles, *abca* or *abcda,* as shown on the PV diagram above. The following information is known about this system.

$Q_{c\to a}$ = 685 J along the curved path
$W_{c\to a}$ = –120 J along the curved path
$U_a - U_b$ = 450 J
$W_{a\to b\to c}$ = 75 J

a. Determine the change in internal energy, $U_a - U_c$, between states *a* and *c*.
b. i. Is heat added to or removed from the gas when the gas is taken along the path *abc ?*

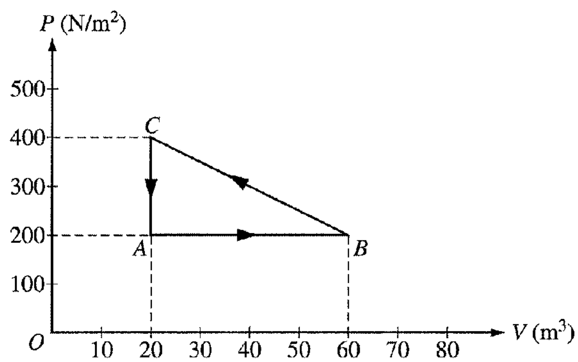
_____added to the gas _____removed from the gas

ii. Calculate the amount added or removed.

c. How much work is done on the gas in the process *cda?*
d. Is heat added to or removed from the gas when the gas is taken along the path *cda?*

_____added to the gas _____removed from the gas

Explain your reasoning.



2003Bb5. One mole of an ideal gas is taken around the cycle $A\to B\to C\to A$ as shown on the PV diagram above.
a. Calculate the temperature of the gas at point *A*.
b. Calculate the net work done on the gas during one complete cycle.
c. i. Is heat added to or removed from the gas during one complete cycle?

_____added to the gas _____removed from the gas

ii. Calculate the heat added to or removed from the gas during one complete cycle.

d. After one complete cycle, is the internal energy of the gas greater, less, or the same as before?

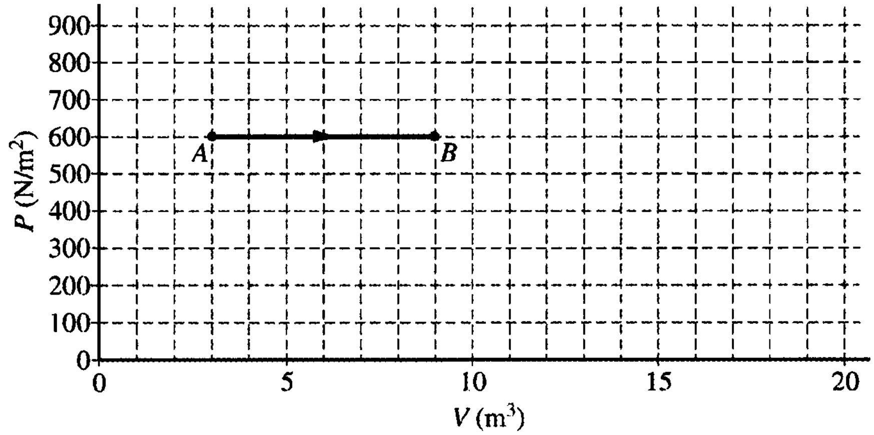
_____greater _____less _____the same

Justify your answer.

e. After one complete cycle, is the entropy of the gas greater, less, or the same as before?

_____greater _____less _____the same

Justify your answer.

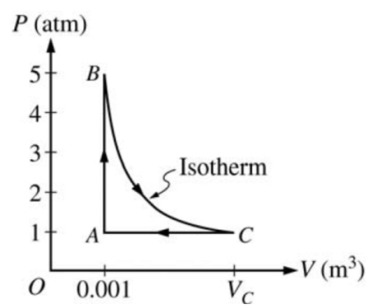


2004B5. The diagram above of pressure P versus volume V shows the expansion of 2.0 moles of a monatomic ideal gas from state A to state B. *As* shown in the diagram, $P_A = P_B = 600$ N/m^2, $V_A = 3.0$ m^3, and $V_B = 9.0$ m^3.

a. i. Calculate the work done by the gas as it expands.
ii. Calculate the change in internal energy of the gas as it expands.
iii. Calculate the heat added to or removed from the gas during this expansion.

b. The pressure is then reduced to 200 N/m^2 without changing the volume as the gas is taken from state B to state C. Label state C on the diagram and draw a line or curve to represent the process from state B to state C.

c. The gas is then compressed isothermally back to state A.
i. Draw a line or curve on the diagram to represent this process.
ii. Is heat added to or removed from the gas during this isothermal compression?
_______added to _______removed from
Justify your answer.

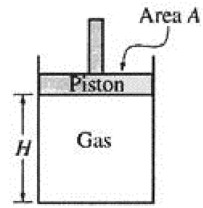


2008B5. A 0.03 mol sample of helium is taken through the cycle shown in the diagram above. The temperature of state A is 400 K.

a. For each process in this cycle, indicate in the table below whether the quantities W, Q, and ΔU are positive (+), negative (–), or zero (0). W is the work done on the helium sample.

Process	W	Q	ΔU
$A \rightarrow B$			
$B \rightarrow C$			
$C \rightarrow A$			

b. Explain your response for the signs of the quantities for process A⇨B.
c. Calculate V_c.

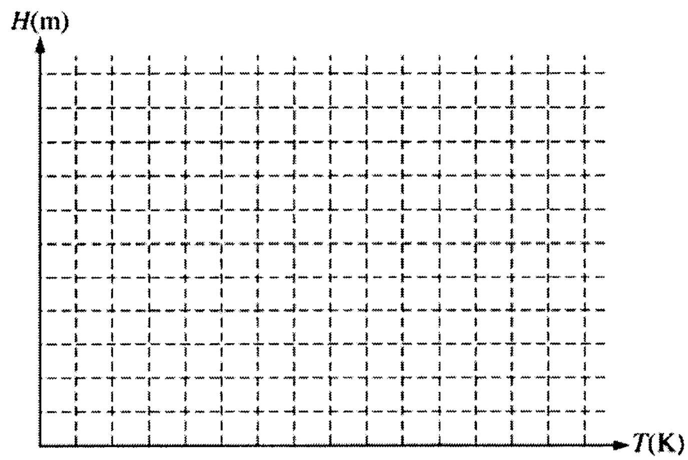


2005B6. An experiment is performed to determine the number n of moles of an ideal gas in the cylinder shown above. The cylinder is fitted with a movable, frictionless piston of area A. The piston is in equilibrium and is supported by the pressure of the gas. The gas is heated while its pressure P remains constant. Measurements are made of the temperature T of the gas and the height H of the bottom of the piston above the base of the cylinder and are recorded in the table below. Assume that the thermal expansion of the apparatus can be ignored.

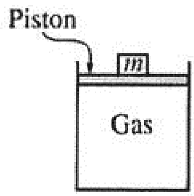
T (K)	H (m)
300	1.11
325	1.19
355	1.29
375	1.37
405	1.47

a. Write a relationship between the quantities T and H, in terms of the given quantities and fundamental constants, that will allow you to determine n.

b. Plot the data on the axes below so that you will be able to determine n from the relationship in part (a). Label the axes with appropriate numbers to show the scale.



c. Using your graph and the values A = 0.027 m^2 and P = 1.0 atmosphere, determine the experimental value of n.



Note: Figure not drawn to scale.

2005Bb6. You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure above. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V. The data collected are given in the table below.

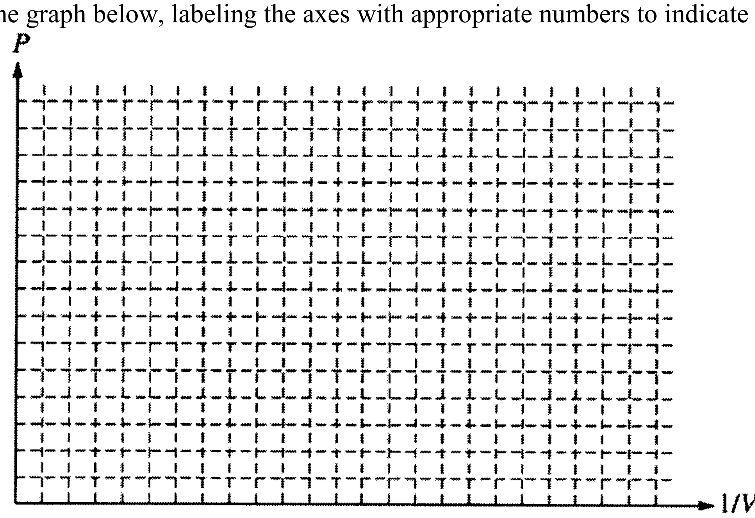
m (kg)	V (m^3)	$1/V$ (m^{-3})	P (Pa)
0	6.0×10^{-5}	1.7×10^{4}	
1	4.5×10^{-5}	2.2×10^{4}	
2	3.6×10^{-5}	2.8×10^{4}	
3	3.0×10^{-5}	3.3×10^{4}	
4	2.6×10^{-5}	3.8×10^{4}	

a. Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

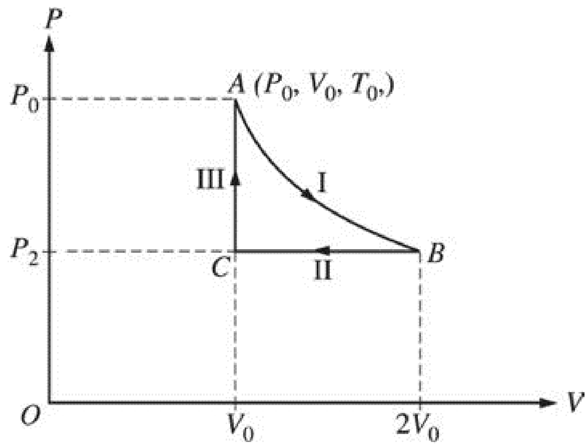
You also determine that $A = 3.0 \times 10^{-4}$ m^2 and $T = 300$ K.

b. Calculate the value of P for each value of m and record your values in the data table above.

c. Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.



d. Using your graph in part (c), calculate the experimental value of n.

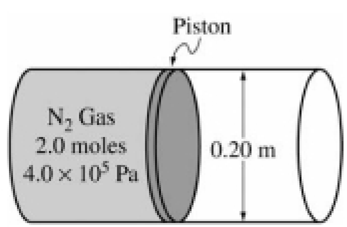


2006Bb5. A sample of ideal gas is taken through steps I, II, and III in a closed cycle, as shown on the pressure P versus volume V diagram above, so that the gas returns to its original state. The steps in the cycle are as follows.

I. An isothermal expansion occurs from point A to point B, and the volume of the gas doubles.
II. An isobaric compression occurs from point B to point C, and the gas returns to its original volume.
III. A constant volume addition of heat occurs from point C to point A and the gas returns to its original pressure.

a. Determine numerical values for the following ratios, justifying your answers in the spaces next to each ratio.
i. $\dfrac{P_B}{P_A} =$ ii. $\dfrac{P_C}{P_A} =$ iii. $\dfrac{T_B}{T_A} =$ iv. $\dfrac{T_C}{T_A} =$

b. During step I, the change in internal energy is zero. Explain why.
c. During step III, the work done on the gas is zero. Explain why.



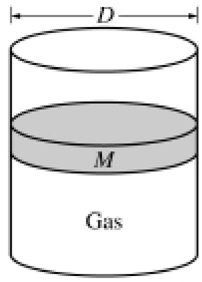
2007B5. The figure above shows a 0.20 m diameter cylinder fitted with a frictionless piston, initially fixed in place. The cylinder contains 2.0 moles of nitrogen gas at an absolute pressure of 4.0×10^5 Pa. Nitrogen gas has a molar mass of 28 g/mole and it behaves as an ideal gas.
a. Calculate the force that the nitrogen gas exerts on the piston.
b. Calculate the volume of the gas if the temperature of the gas is 300 K.
c. In a certain process, the piston is allowed to move, and the gas expands at constant pressure and pushes the piston out 0.15 m. Calculate how much work is done <u>by the gas</u>.
d. Which of the following is true of the heat energy transferred to or from the gas, if any, in the process in part (c)?

_______Heat is transferred to the gas.

_______Heat is transferred from the gas.

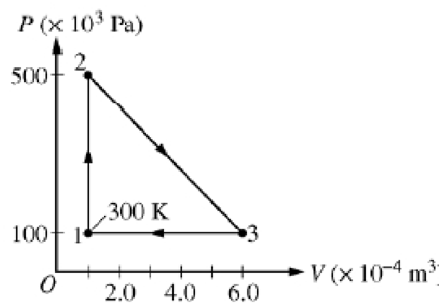
_______No heat is transferred in the process.

Justify your answer.



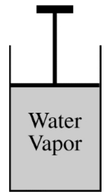
B2007b5. The cylinder above contains an ideal gas and has a movable, frictionless piston of diameter D and mass M. The cylinder is in a laboratory with atmospheric pressure P_{atm} . Express all algebraic answers in terms of the given quantities and fundamental constants.

a. Initially, the piston is free to move but remains in equilibrium. Determine each of the following.
   i. The force that the confined gas exerts on the piston
   ii. The absolute pressure of the confined gas
b. If a net amount of heat is transferred to the confined gas when the piston is fixed, what happens to the pressure of the gas?
   _______Pressure goes up. _______Pressure goes down. _______Pressure stays the same.
   Explain your reasoning.
c. In a certain process the absolute pressure of the confined gas remains constant as the piston moves up a distance x_o. Calculate the work done by the confined gas during the process.

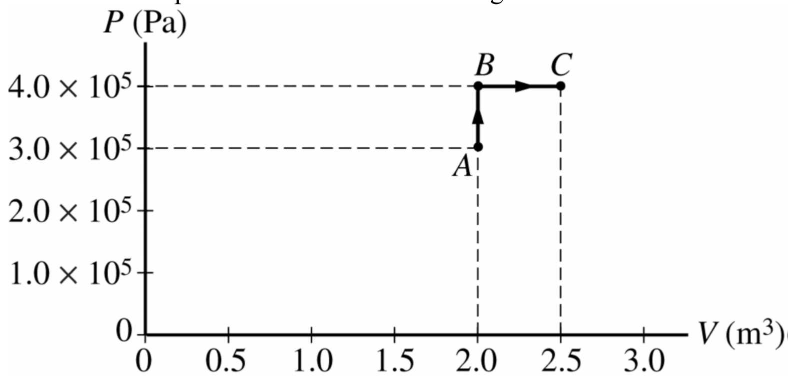


2008Bb6. A 0.0040 mol sample of a monatomic gas is taken through the cycle shown above. The temperature T_1 of state 1 is 300 K.

a. Calculate T_2 and T_3.
b. Calculate the amount of work done on the gas in one cycle.
c. Is the net work done on the gas in one complete cycle positive, negative, or zero?
   _____Positive _____Negative _____Zero
d. Calculate the heat added to the gas during process 1→2.



2009B4. The cylinder represented above contains 2.2 kg of water vapor initially at a volume of 2.0 m^3 and an absolute pressure of 3.0×10^5 Pa. This state is represented by point *A* in the *PV* diagram below. The molar mass of water is 18 g, and the water vapor can be treated as an ideal gas.

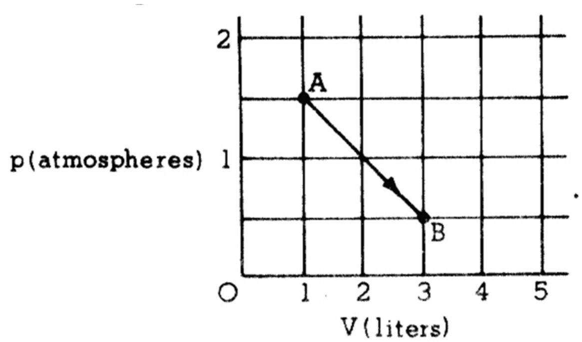


a. Calculate the temperature of the water vapor at point *A*.

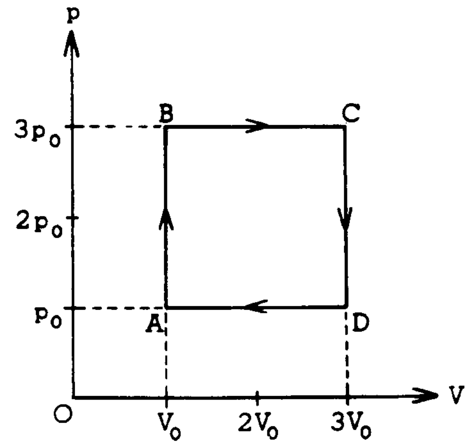
The absolute pressure of the water vapor is increased at constant volume to 4.0×10^5 Pa at point *B*, and then the volume of the water vapor is increased at constant pressure to 2.5 m^3 at point *C*, as shown in the *PV* diagram.

b. Calculate the temperature of the water vapor at point *C*.
c. Does the internal energy of the water vapor for the process *A→B→C* increase, decrease, or remain the same?
____Increase ____Decrease ____Remain the same
Justify your answer.
d. Calculate the work done on the water vapor for the process *A→B→C*.

1974B6. One-tenth of a mole of an ideal monatomic gas undergoes a process described by the straight-line path AB shown in the p-V diagram below.

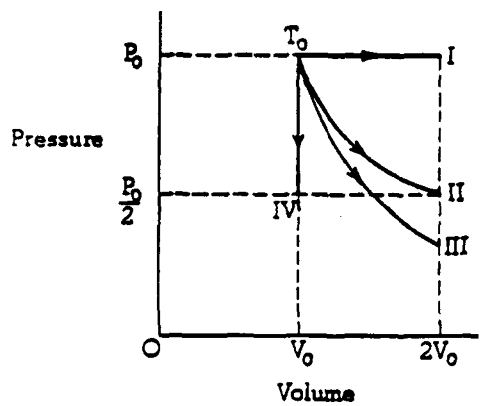


a. Show that the temperature of the gas is the same at points A and B.
b. How much heat must be added to the gas during the process described by A $\rightarrow$ B?
c. What is the highest temperature of the gas during the process described by A $\rightarrow$ B?



1975B3. One mole of a monatomic ideal gas enclosed in a cylinder with a movable piston undergoes the process ABCDA shown on the p-V diagram above.

a. In terms of p_o and V_o calculate the work done on the gas in the process.
b. In terms of p_o and V_o calculate the net heat absorbed by the gas in the process.
c. At what two lettered points in the process are the temperatures equal? Explain your reasoning.
d. Consider the segments AB and BC. In which segment is the amount of heat added greater? Explain your reasoning.

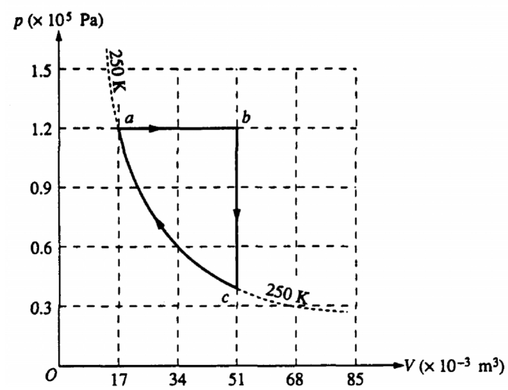


1979B5. Four samples of ideal gas are each initially at a pressure P_o and volume V_o, and a temperature T_o as shown on the diagram above. The samples are taken in separate experiment from this initial state to the final states I, II, III, and IV along the processes shown on the diagram.

a. One of the processes is isothermal. Identify which one and explain.
b. One of the processes is adiabatic. Identify this one and explain.
c. In which process or processes does the gas do work? Explain.
d. In which process or processes is heat removed from the gas? Explain.
e. In which process or processes does the root-mean-square speed of the gas molecules increase? Explain.

1991B3 (modified) A heat engine consists of an oil-fired steam turbine driving an electric power generator with a power output of 120 megawatts. The thermal efficiency of the heat engine is 40 percent.

a. Determine the time rate at which heat is supplied to the engine.
b. If the heat of combustion of oil is 4.4×10^7 joules per kilogram, determine the rate in kilograms per second at which oil is burned.
c. Determine the time rate at which heat is discarded by the engine.



1993B5. One mole of an ideal monatomic gas is taken through the cycle abca shown on the diagram above. State a has volume $V_a = 17 \times 10^{-3}$ cubic meter and pressure $P_a = 1.2 \times 10^5$ pascals, and state c has volume $V_c = 51 \times 10^{-3}$ cubic meter. Process ca lies along the 250 K isotherm. Determine each of the following.

a. The temperature T_b of state b

b. The heat Q_{ab} added to the gas during process ab

c. The change in internal energy $U_b - U_a$

d. The work W_{bc} done by the gas on its surroundings during process bc

The net heat added to the gas for the entire cycle 1,800 joules. Determine each of the following.

e. The net work done on the gas by its surroundings for the entire cycle

f. The efficiency of a Carnot engine that operates between the maximum and minimum temperatures in this cycle

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1995B5. A heat engine operating between temperatures of 500 K and 300 K is used to lift a 10-kilogram mass vertically at a constant speed of 4 meters per second.

a. Determine the power that the engine must supply to lift the mass.

b. Determine the maximum possible efficiency at which the engine can operate.

c. If the engine were to operate at the maximum possible efficiency, determine the following.

i. The rate at which the hot reservoir supplies heat to the engine

ii. The rate at which heat is exhausted to the cold reservoir

ANSWERS - AP Physics Multiple Choice Practice – Thermodynamics

	Solution	Answer
1.	While *all* collisions are elastic and $K_{avg} \propto T$, the molecules move with a wide range of speeds represented by the Maxwellian distribution.	B
2.	For X⇨Y, the process is isobaric. Since the gas is expanding, W < 0 and since the temperature is increasing, ΔU > 0 and ΔU = Q + W so Q > 0 (it is also true because process XY lies above an adiabatic expansion from point X)	C
3.	For Y⇨Z, the process is isochoric, which means no work is done (W = 0) and since the temperature is increasing, ΔU > 0	C
4.	$PV \propto T$, or $P \propto T/V$ and if T × 2 then P × 2 and if V × 4 then P ÷ 4 so the net effect is P×2÷4	C
5.	$PV \propto T$ so to triple the temperature, the product of P and V must be tripled	A
6.	Changes in internal energy are path independent on a pV diagram as it depends on the change in temperature, which is based on the beginning and end points of the path and not the path taken	B
7.	$K_{avg} \propto T$	C
8.	$H = \frac{kA\Delta T}{L}$	B
9.	No work is done in an isochoric process, or a process where ΔV = 0 (a vertical line on the pv graph)	A
10.	The temperature at any point is proportional to the product of P and V. Point A at temperature T_0 is at pressure × volume p_0V_0. Point C is at $3p_0 \times 3V_0 = 9T_0$ and point D is at $2p_0 \times 4V_0 = 8T_0$	C
11.	For the entire cycle, ΔU = 0 and W = –8 J so Q = ΔU – W = +8 J (8 J added). This means $Q_{AB} + Q_{BC} + Q_{CA}$ = +8 J = +12 J + 0 J + Q_{CA} = +8 J	B
12.	Q = +275 J; W = + 125 J + (– 50 J) = +75 J; ΔU = Q + W	C
13.	Work is the area under the curve, the line bounding the greatest area indicates the most work done	A
14.	Temperature rises as you travel up and to the right on a pV diagram. Since processes 1, 2 and 3 are at the same volume, the highest point is at the highest temperature	A
15.	Q = +400 J; W = – 100 J; ΔU = Q + W	B
16.	Isothermal means the temperature is constant. Points to the right or above are at higher temperatures.	B,C
17.	$P \propto T$ at constant volume. If T × 2, then P × 2. Since the mass and volume are unchanged, the density is unchanged as well	C
18.	If the collisions were inelastic, the gas would change its temperature by virtue of the collisions with no change in pressure or volume.	D
19.	related to average speed, $v_{rms} = \sqrt{\frac{3RT}{M}}$	C
20.	Being in thermal equilibrium means the objects are at the same temperature. Mass is irrelevant. The question describes the zeroth law of thermodynamics.	C

21. Changes in internal energy are path independent on a pV diagram as it depends on the change in temperature, which is based on the beginning and end points of the path and not the path taken. Different paths, with different areas under them will do different amounts of work and hence, different amounts of heat exchanged. A

22. In linear expansion, every linear dimension of an object changes by the same fraction when heated or cooled. C

23. “rigid container” = constant volume. If the speed increases, the temperature will increase, and if the temperature increases at constant volume, the pressure will increase. C

24. $H = \frac{kA\Delta T}{L}$ D

25. Q = –16 J; W = –32 J; ΔU = Q + W A

26. $P \propto nT/V$; if $n \times 3$ then $P \times 3$ and if $T \times 2$ then $P \times 2$, the net effect is $P \times 3 \times 2$ D

27. ΔU for each process is equal so $Q_{AC} + W_{AC} = Q_{ABC} + W_{ABC}$, or +30 J + (–20 J) = +25 J + W_{ABC} C

28. In any compression, work is done on the gas (W is +). Since the compression is isothermal, ΔU = 0 so Q = –W and heat leaves the gas. A

30. $K_{avg} \propto T$ C

31. In linear expansion, every linear dimension of an object changes by the same fraction when heated or cooled. A

32. $K_{avg} \propto T$ D

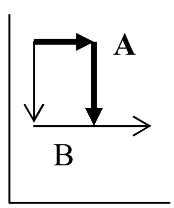
33. $P \propto n/V$ at constant temperature A

34. This question is a bit of a paradox as the energy form the fan giving the air kinetic energy is theoretically adding to the thermal energy of the air, But as the air lowers in temperature, this energy will dissipate into the walls and other outside areas of the room as thermal energy as well. A

35. $K_{avg} \propto T$ B

36. Gas escaping form a pressurized cylinder is an example of an adiabatic process. While the gas rapidly does work (W < 0), ΔU is negative since heat does not have time to flow into the gas in a rapid expansion. A

37. Since process A and B perform the same amount of work, they must have the same area under their respective lines. Since A does the work at a higher pressure, it does not have to move as far to the right as process B, which performs the work at a lower temperature. Since the end of process B lies farther to the right, it is at the higher temperature. B



38. At constant pressure $V \propto T$ (use absolute temperature) C

39. Metals are the best heat conductors and will conduct heat out of the hamburger quickly A

40.	Consider the isothermal line as the "dividing line" between process that increase the temperature of the gas (above the isotherm) and process that lower the temperature of the gas (below the isotherm). A similar analysis can be done to identify heat added or removed from a gas by comparing a process to an adiabat drawn from the same point.	C,D
41.	$K_{avg} = 3/2\ k_B T$ (use absolute temperature)	C
42.	In linear expansion, every linear dimension of an object changes by the same fraction when heated or cooled. Since each side increases by 4%,the area increases by $(1.04)^2 = 1.08$	A
43.	$pV = nRT$ and $n = N/N_A$	B
44.	$K_{avg} \propto T$ (absolute)	D
45.	$Q_{abd} = +60\text{ J} + 20\text{ J} = +80\text{ J}$. W_{abd} = area, negative due to expansion = –24 J so $\Delta U = Q + W = +56\text{ J}$ and $\Delta U_{abd} = \Delta U_{acd}$ and W_{acd} = area = –9 J so $Q_{acd} = \Delta U - W_{acd} = +56\text{ J} - (-9\text{ J})$	B
46.	Since there is no area under the line (and no change in volume) W = 0. The temperature (and internal energy) decrease so Q cannot be zero ($Q = \Delta U - W$)	C
47.	$pV = nRT$	D
48.	Pressure is the collisions of the molecules of the gas against the container walls. Even though the speed of the molecules is unchanged (constant temperature), the smaller container will cause the molecules to strike the walls more frequently.	B
49.	Q = 0 in adiabatic processes (choices B and D). $Q = \Delta U - W$. Choices A and C have the same ΔT and hence, same ΔU and since doubling the volume at constant pressure involves *negative* work, while doubling the pressure at constant volume does *no* work, $\Delta U - W$ is greater for the constant pressure process. (The constant temperature process has $\Delta U = 0$ and less work than the constant pressure process)	A
50.	$pV = nRT$ (watch those units!)	C
51.	Isochoric cooling is a path straight down on a pV diagram (to lower pressures)	A
52.	Work = area under the curve on a *pV diagram*. In the convention stated, work is negative for any expansion. Be careful with the graph since it is a graph of pressure vs. *temperature*. We can find the work by using $\lvert W\rvert = p\Delta V = nR\Delta T$	D
53.	Work = area enclosed by the parallelogram. Since the work done *on* the gas is negative for a clockwise cycle and they are asking for the work done *by* the gas, the answer will be positive.	B
54.	At constant volume $\Delta U = Q = 3/2\ nR\Delta T$ where in an isochoric process $nR\Delta T = \Delta pV$ so $Q = 3/2\ \Delta pV$, or $\Delta p = 2 \times (+40\text{ J})/(3 \times 0.008\text{ m}^3)$	C
55.	$v_{rms} = \sqrt{\frac{3RT}{M}}$ Since hydrogen is 16 times lighter and $v_{rms} \propto \frac{1}{\sqrt{M}}$, $v_H = 4 \times v_O$	B
56.	$v_{rms} = \sqrt{\frac{3RT}{M}}$ since $M_O > M_H$ for them to have the same v_{rms} $T_O > T_H$	D
57.	$v_{rms} = \sqrt{\frac{3RT}{M}}$ if v_{rms} is doubled, then T is quadrupled. If T × 4 at constant volume, then p × 4	D
58.	The "energy" lost or gained would be the sum of the work done on the gas and the net heat added to the gas, which is the change in internal energy of the gas. Since the gas returns to its original state, $\Delta U = 0$.	A, B

59. $$H = \frac{kA\Delta T}{L}$$ A,D

60. An adiabatic expansion is shaped like an isotherm, but brings the gas to a lower temperature. C

61. $Q_{cycle} = Q_{12} + Q_{23} + Q_{31} = +60\ J – 40\ J + 0\ J = +\ 20\ J$ D
$W_{cycle} = \Delta U_{cycle} – Q_{cycle} = 0\ J – (+20\ J) = –20\ J = W_{12} + W_{23} + W_{31}$
where $W_{12} = –Q_{12}$ since $\Delta U_{12} = 0$ and $W_{23} = 0$
so we have $–20\ J = –60\ J + 0\ J + W_{31}$ which gives $W_{31} = +40\ J$
Process 3⇨1 is adiabatic so $\Delta U_{31} = W_{31}$

1983B4

a. Since T is constant, $p_BV_B = p_0V_0$ and $V_B = 2V_0$ gives $p_B = ½\ p_0$

b. $\Delta U = Q + W$, since AB is isothermal, $\Delta U = 0$ and $W = –Q = –1000$ J

c. The entropy of the gas increases because $\Delta S = Q/T$ and Q is positive (heat was added)

d. In a reversible (Carnot) engine $\frac{Q_H}{Q_C} = \frac{T_H}{T_C}$ giving $Q_c = 400$ J

e. Negative. In a clockwise cycle, the work done on the gas is negative. Or for the cycle $Q_{net} = +600$ J and $\Delta U = 0$ so $W = –Q = – 600$ J

1996B7

a. $p_1/T_1 = p_2/T_2$ gives $p_2 = 0.82$ atm $= 8.2 \times 10^4$ Pa

b. $F = p \times$ Area $= 410$ N

c. Since volume and temperature are constant, we can use $p_1V = n_1RT$ and $p_2V = n_2RT$. SUbtractnig the two equations gives $\Delta pV = \Delta nRT$, or $\Delta n = \Delta pV/RT = 5.45 \times 10^{-3}$ mol

1986B5

a. $e_c = \frac{T_H - T_C}{T_H}$ (use absolute temperature) gives $e_c = 0.074$

b. $e = W/Q_H$, or $Q_H = W/e = (100\text{ MW})/(0.074) = 1350$ MW and $Q_C = Q_H – W = 1250$ MW (note Q may represent heat in Joules or rate in Watts)

c. AB is isothermal so $\Delta T = 0$. It is an expansion so W is – and $Q = –W$
BC is adiabatic so $Q = 0$. Temperature drops so ΔT is negative.
CD is isothermal so $\Delta T = 0$. It is a compression so W is + and $Q = –W$
BC is adiabatic so $Q = 0$. Temperature rises so ΔT is positive.

	Q	ΔT
AB	+	0
BC	0	–
CD	–	0
DA	0	+

2004B5B

a. Since $P_A = P_B$ and $V_A/T_A = V_B/T_B$ giving $T_B = T_2 = T_1/2$

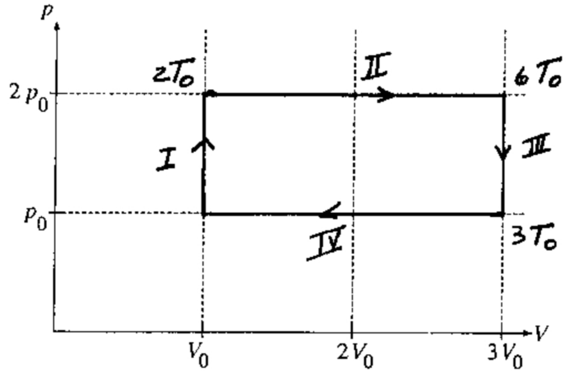
b. CA is an isotherm so $T_A = T_C$ so $P_AV_A = P_CV_C$; $P_1V_1 = P_2(V_1/2)$ giving $P_2 = 2P_1$

c. Work is the area under the line. No work is done from B to C so we just need the area under line AB.
Specifically, $W = –P\Delta V = –P_1(V_1/2 – V_1) = +½P_1V_1$

d. Heat was added in processes BC and CA, but not in AB.
BC: $W = 0$ so $\Delta U = Q$ and temperature rises so ΔU is positive
CA: $\Delta U = 0$ (isotherm) so $Q = –W$ and it is an expansion so W is negative and therefore Q is positive
AB: Compression so W is + and temperature drops so ΔU is negative and $Q = \Delta U – W$ which must be negative

1989B4

a.



b. i. The work done on the gas is the area enclosed. Area = width × height = $2V_0 \times P_0 = -2P_0V_0$ (negative since it is a clockwise cycle)

ii. $\Delta U = 0$ for any cycle

iii. since $\Delta U = 0$, $Q = -W = +2P_0V_0$

c. For process 2, $W = -P\Delta V = -2P_0 \times (3V_0 - V_0) = -4P_0V_0$

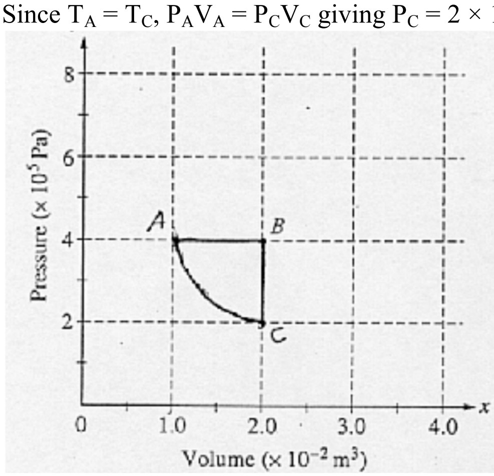
and $\Delta U = 3/2\ nR\Delta T = 3/2\ nR(6T_0 - 2T_0) = +6\ nRT_0 = +6P_0V_0$

$Q = \Delta U - W = +6\ P_0V_0 - (-4P_0V_0) = +10P_0V_0$

1999B7

a. Since $T_A = T_C$, $P_AV_A = P_CV_C$ giving $P_C = 2 \times 10^5$ Pa

b.



c. This is a clockwise cycle so the work done on the gas is negative.

d. This is a clockwise cycle so this is a heat engine.

2001B6

a. The additional pressure comes from the weight of the added block. $\Delta P = F/A = mg/A = 2.04 \times 10^3$ Pa and $P_2 = P_1 + \Delta P = 1.04 \times 10^5$ Pa

b. A constant temperature, $P_1V_1 = P_2V_2$, or $V_2 = P_1V_1/P_2 = 1.47 \times 10^{-3}$ m^3

c. Since the external pressure and the added weight do not change, the pressure remains constant, therefore the process from state 2 to state 3 is isobaric

d. For similar reasons as stated above, the process from state 4 to state 1 is also isobaric.

e. Comparing state 1 and state 4, which have equal pressures: $V_1/T_1 = V_4/T_4$, giving $V_4 = V_1T_4/T_1 = 2.05 \times 10^{-3}$ m^3

2006B5

a. i. $P_1 = P_2$ so $V_1/T_1 = V_2/T_2$ giving $T_2 = 746$ K

ii. $V_1 = V_3$ so $P_1/T_1 = P_3/T_3$ giving $T_3 = 560$ K

b. The net work done is the area enclosed by the triangle = ½ base × height = +6250 J (positive since the cycle is counterclockwise)

c. Since the cycle is counterclockwise, the work done on the gas is positive (more area under the process 2⇨3 in which positive work is done than in process 1⇨2 where negative work is done). In any cycle $\Delta U = 0$ so we have $Q = -W$, therefore Q is negative meaning heat is removed.

2003B5

a. $U_a - U_c = \Delta U_{ca} = Q_{ca} + W_{ca} = 685\text{ J} + (-120\text{ J}) = 565\text{ J}$

b. i/ii. Heat is removed. $\Delta U_{abc} = -\Delta U_{ca} = -565$ J since it is the opposite beginning and end points, the path doesn't matter. $Q = \Delta U - W = -565\text{ J} - 75\text{ J} = -640\text{ J}$

c. $W_{cda} = W_{cd} + W_{da} = 0 + -P\Delta V_{da} = -150\text{ J}$

d. Heat is added. $\Delta U = +565$ J and $W = -150$ J and $Q = \Delta U - W$

2003B5B

a. $pV = nRT$ so $T = pV/nR = (200\text{ Pa})(20\text{ m}^3)/(1\text{ mol})(8.32\text{ J/(mol-K)}) = 481\text{ K}$

b. The net work done is the area enclosed by the triangle = ½ base × height = +4000 J (positive since the cycle is counterclockwise)

c. i/ii. Heat is removed. In one cycle $\Delta U = 0$ so $Q = -W = -4000$ J

d. In a cyclic process $\Delta U = 0$ (the temperature returns to the same value)

e. The entropy is a function of the state of the gas, and after one complete cycle the gas has returned to its original state so the entropy is the same.

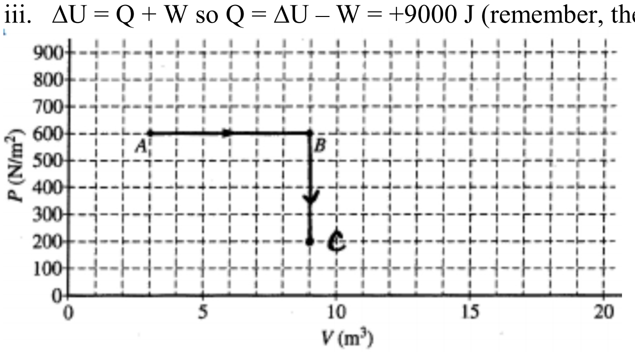
2004B5

a. i. $W = -P\Delta V = -3600$ J. The work done *by* the gas is the negative of the work done *on* the gas, +3600 J

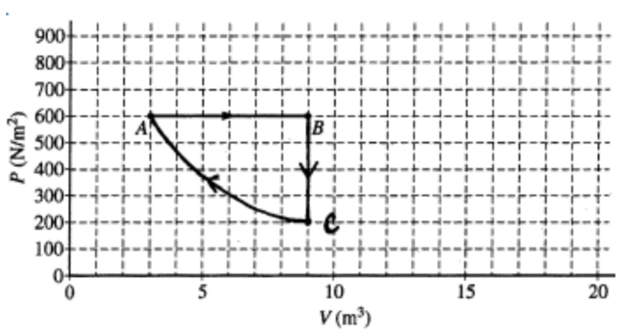
ii. $\Delta U = 3/2\ nR\Delta T$ and the temperatures can be found from $PV = nRT$ giving $T_A = 108$ K and $T_B = 325$ K so $\Delta U = 5400$ J

iii. $\Delta U = Q + W$ so $Q = \Delta U - W = +9000$ J (remember, the W in this equation is the work done *on* the gas)

b.



c.



ii. Heat is removed. In an isothermal process, $\Delta U = 0$ so $Q = -W$ and in a compression W is positive.

2008B5

a.

Process	W	Q	ΔU
$A \rightarrow B$	0	+	+
$B \rightarrow C$	–	+	0
$C \rightarrow A$	+	–	–

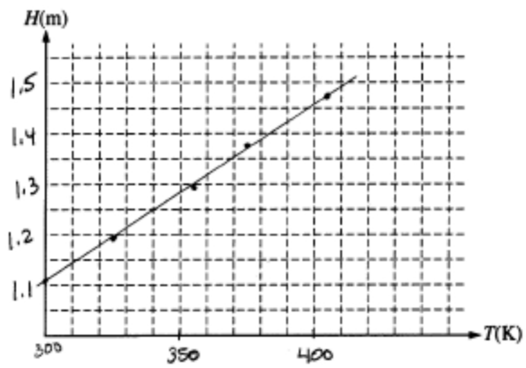
b. ⇨Since process AB is isochoric, $\Delta V = 0$ therefore $W = -P\Delta V = 0$ (also, there is no area under the line)
⇨At constant volume for a fixed number of moles, pressure is directly related to temperature and since the pressure increases, so does the temperature. ΔU is directly related to ΔT so it is positive.
⇨$Q = \Delta U - W$ and $W = 0$

c. Since $T_B = T_C$, $P_BV_B = P_CV_C$ so $V_C = P_BV_B/P_C = 0.005\ m^3$

2005B6

a. The volume of the cylinder = Area × height = AH. PV = nRT then becomes PAH = nRT so H = nRT/PA

b.



c. Calculating the slope of the line above and setting it equal to the slope from the equation of part a: nR/PA gives n = 1.11 moles

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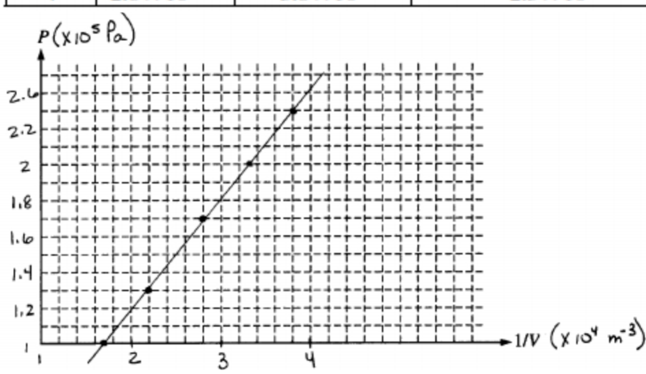
2005B6B

a. PV = nRT or P = (1/V)nRT

b. The total pressure is the atmospheric pressure plus the pressure due to the added mass $P = P_{atm} + mg/A$

m (kg)	V (m^3)	$1/V$ (m^{-3})	P (Pa)
0	6.0×10^{-5}	1.7×10^4	1.0×10^5
1	4.5×10^{-5}	2.2×10^4	1.3×10^5
2	3.6×10^{-5}	2.8×10^4	1.7×10^5
3	3.0×10^{-5}	3.3×10^4	2.0×10^5
4	2.6×10^{-5}	3.8×10^4	2.3×10^5

c.



d. From P = (1/V)nRT, the slope of the above line = nRT. Slope = 6.19 Pa-m^3 so n = .0025 moles

2006B5B

a. i. $T_A = T_B$ so $P_AV_A = P_BV_B$: $P_B/P_A = ½$
   ii. $P_B = P_C$ so $P_C/P_A = P_B/P_A = ½$
   iii. A and B are on the same isotherm so $T_B/T_A = 1$
   iv. $V_C = V_A$ so $P_C/P_A = T_C/T_A = ½$

b. Internal energy depends only on the temperature. Since step I is isothermal there is no change in temperature and thus no change in internal energy

c. $W = -P\ \Delta V$. In step III there is no change in volume, and thus no work done.

2007B5

a. $P = F/A$ so $F = PA = P(\pi R^2) = (4.0 \times 10^5\ \text{Pa})\pi(½\ 0.20\ \text{m})^2 = 1.3 \times 10^4\ \text{N}$

b. $PV = nRT$ gives $V = 1.2 \times 10^{-2}\ \text{m}^3$

c. $W_{\text{on the gas}} = -P\Delta V$ so $W_{\text{by the gas}} = +P\Delta V$ where $\Delta V = Ax = \pi R^2x$ and x = extra distance pushed by the piston giving $W_{by} = 1.9 \times 10^3$ J

d. Heat is transferred to the gas. This is an expansion so W_{on} is negative. For the gas to expand at constant pressure, the temperature must also increase so ΔU is positive. $Q = \Delta U - W$.

2007B5B

a. i. For the piston to be in equilibrium, the gas must hold it up against its own weight and the external force due to the outside pressure: $F = P_{atm}A + Mg$ where $A = \pi R^2 = \pi(D/2)^2 = \pi D^2/4$ so we have $F = ¼P_{atm}\pi D^2 + Mg$
   ii. $P = F/A = F$ from above $\div ¼\pi D^2$ giving $P_{abs} = P_{atm} + 4Mg/\pi D^2$

b. Pressure goes up. If heat is added at constant volume, the temperature goes up and so must the pressure since $P \propto T$ at constant volume.

c. $W = Fx$ (from mechanics) $= (¼P_{atm}\pi D^2 + Mg)x_0$

2008B6B

a. $V_1 = V_2$ so $P_1/T_1 = P_2/T_2$ giving $T_2 = 1500$ K; $P_1 = P_3$ so $V_1/T_1 = V_3/T_3$ giving $T_3 = 1800$ K

b/c. The net work done is the area enclosed by the triangle = ½ base × height = –100 J (negative since clockwise)

d. For process 1⇨2 W = 0 so $Q = \Delta U = 3/2\ nR\Delta T = (1.5)(0.004\ \text{mol})(8.31\ \text{J/mol-K})(1500\ \text{K} - 300\ \text{K}) = 60$ J

2009B4

a. $PV = nRT$ so $T = PV/nR$ and the number of moles = $(2.2 \times 10^3$ g of $H_2O)/(18$ g/mole$) = 122.2$ moles. This gives $T = (3 \times 10^5\ \text{Pa})(2\ \text{m}^3)/(122.2\ \text{moles})(8.31\ \text{J/mol-K}) = 591$ K

b. The temperature is proportional to the product of P and V. $(PV)_A = 6 \times 10^5$ J and $(PV)_C = 10 \times 10^5$ J so $T_C/T_A = 10/6$ giving $T_C = 985$ K

c. Since the temperature increases for process A⇨B⇨C and U is dependent on the temperature, U increases.

d. $W_{ABC} = W_{AB} + W_{BC} = 0 + -P\Delta V = -(4 \times 10^5\ \text{Pa})(2.5\ \text{m}^3 - 2\ \text{m}^3) = -2 \times 10^5$ J

1974B6

a. $P_AV_A/T_A = P_BV_B/T_B$; $(1.5\ \text{atm})(1\ \text{L})/T_A = (0.5\ \text{atm})(3\ \text{L})/T_B$ giving $T_A = T_B$

b. Since $T_A = T_B$, $\Delta U_{AB} = 0$. W is the area under the line = –2 L-atm (negative for an expansion) and we have $Q = \Delta U - W = +2$ L-atm = +202.6 J

c. PV/T is constant so highest temperature is at the highest value of PV where P = 1 atm and V = 2 L. $PV = nRT$ gives T = 243 K

1975B3

a. The work done on the gas is the area enclosed by the cycle = length×width = $-4p_0V_0$ (negative since clockwise)

b. In the cycle $\Delta U = 0$ so $Q = -W = +4p_0V_0$

c. Temperature is the same where the product p × V is the same: $A = p_0V_0$; $B = 3p_0V_0$; $C = 9p_0V_0$; $D = 3p_0V_0$; $T_B = T_D$

d. AB: $Q = \Delta U - W = 3/2\ nR\Delta T - 0$ and $\Delta T = 2T_0$; so $Q = +3nRT_0 = +3p_0V_0$
   BC: $Q = \Delta U - W = 3/2\ nR\Delta T - (-p\Delta V)$ and $\Delta T = 6T_0$; so $Q = 9p_0V_0 - (-6p_0V_0) = +15p_0V_0$
   $Q_{BC} > Q_{AB}$

1979B5

a. Process II is isothermal. An isothermal process is one in which the temperature is constant. Thus, from the ideal gas law, the product of pressure and volume is a constant. This condition is satisfied by process II.

b. Process III is adiabatic. In an adiabatic process, both the pressure and the volume must change. Thus, processes I and IV are eliminated. Since process II is isothermal, process III is the only possible adiabatic one.

c. The gas does work in processes I, II and III. Work is done by the gas whenever the volume increases. (negative work is done by the gas when the volume decreases as well)

d. In process IV, no work is done. Since the pressure decreases at constant volume, the temperature also decreases, giving ΔU is negative and with $W = 0$, $\Delta U = Q$ and therefore Q is negative. One could also use the adiabatic process as the dividing line between process in which heat is added and those for which heat is removed. On the adiabatic line, $Q = 0$. For any process from the same initial point that lies above the adiabat, heat is added and for any process that lies below the adiabat, heat is removed.

e. RMS speed is proportional to the kinetic energy which, in turn, is proportional to the temperature. Only in process I does the temperature increase.

1991B3

a. Power is the rate of useful work form an engine so W (which here represents the rate in MW) = 120 MW and $e = W/Q_H = 0.40 = 120\text{ MW}/Q_H$ giving $Q_H = 300$ MW

b. The rate of heat input from the combustion of oil is 300 Joules per second. Since oil provides 4.4×10^7 joules per kilogram burned we can divide to find the number of kg per second that must be combusted:
$\Delta m/\Delta t = (300 \times 10^6 \text{ J/s}) \div (4.4 \times 10^7 \text{ J/kg}) = 6.82$ kg/s

c. $Q_C = Q_H - W = 180$ MW

1993B5

a. Since $P_a = P_b$, $V_a/T_a = V_b/T_b$ giving $T_b = 750$ K

b/c. $\Delta U_{ab} = 3/2\ nR\Delta T = (1.5)(1\text{ mole})(8.32\text{ J/mol-K})(750\text{ K} - 250\text{ K}) = 6240$ J
$W_{ab} = -P\Delta V = -(1.2 \times 10^5\text{ Pa})(51 \times 10^{-3}\text{ m}^3 - 17 \times 10^{-3}\text{ m}^3) = -4080$ J
$Q = \Delta U - W = 10{,}320$ J

d. $W = -P\Delta V = 0$ (no area under the line)

e. In a cycle $\Delta U = 0$ so $W = -Q = -1800$ J

f. $e_c = \dfrac{T_H - T_C}{T_H} = 0.66$

1995B5

a. P = Fv (from mechanics) = mgv = (10 kg)(10 m/s^2)(4 m/s) = 400 W

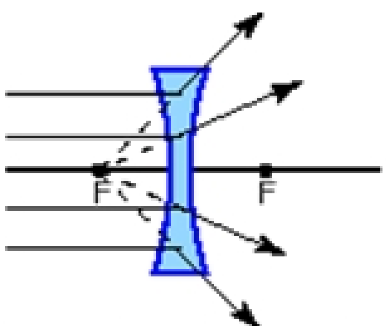
b. $e_c = \dfrac{T_H - T_C}{T_H} = 0.4$ or 40%

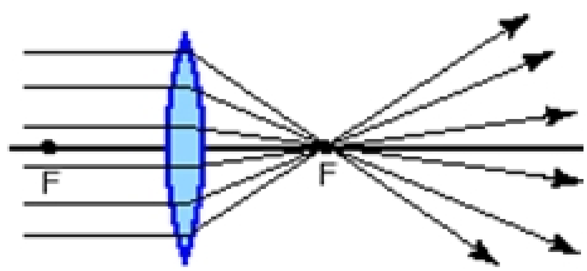
c. i. With an efficiency of 0.4 and useful work done at the rate of 400 W we have $e = (W/t)/(Q_H/t)$ or $(Q_H/t) =$ 1000 W

ii. $(Q_C/t) = Q_H/t) - (W/t) = 600$ W

Chapter 17

Optics





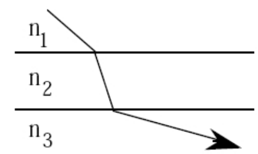
AP Physics Multiple Choice Practice – Optics

SECTION A – Geometric Optics

1. An object is located 0.20 meters from a converging lens which has a focal length of 0.15 meters. Relative to the object, the image formed by the lens will be:
(A) virtual, inverted, smaller (B) real, inverted, smaller. (C) real, inverted, larger
(D) virtual, upright, larger

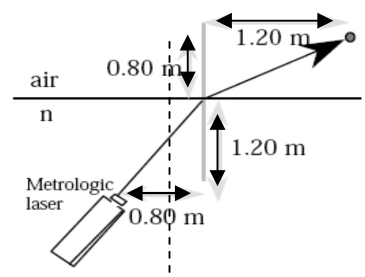
2. Light that has a wavelength of 500 nm in air has a wavelength 400 nm in a transparent material. What is the index of refraction of the material?
(A) 0.64 (B) 0.80 (C) 1.00 (D) 1.25

3. A beam of light passes from medium 1 to medium 2 to medium 3 as shown in the accompanying figure. What is true about the respective indices of refraction (n_1, n_2, and n_3)
(A) $n_1 > n_2 > n_3$ (B) $n_1 > n_3 > n_2$ (C) $n_2 > n_3 > n_1$
(D) $n_2 > n_1 > n_3$

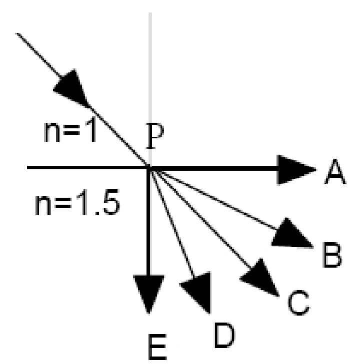


4. A laser is embedded in a material of index of refraction n. The laser beam emerges from the material and hits a target. See the accompanying figure for the position parameters of the laser and target. The value of n is:

(A) 1.4 (B) 1.5 (C) 2.1 (D) 3.5



5. A beam of light is directed toward point P on a boundary as shown to the right. Which segment best represents the refracted ray?
(A) PA (B) PB (C) PC (D) PD

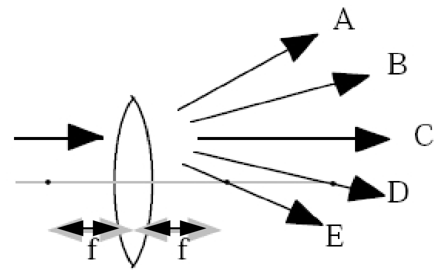


6. **Multi Correct.** Which of the following are possible for the images formed by the lens in the accompanying figure? Select two answers.

(A) real and inverted
(B) real and smaller in size
(C) real and upright
(E) virtual and smaller in size

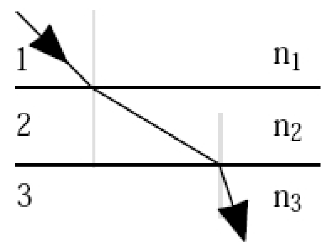
7. A narrow beam of monochromatic light enters a lens parallel to the optic axis, as shown in the accompanying diagram. Which arrow best represents the direction of the light after leaving the lens?
(A) arrow A (B) arrow B

(C) arrow D (D) arrow E

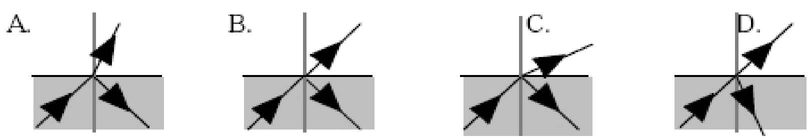


8. The accompanying diagram shows the path that a light ray takes passing through three transparent materials. The indices of refraction in materials 1, 2, and 3 are n_1, n_2, and n_3, respectively. Which of the following best describes the relation between the indices of refraction?

(A) $n_1 > n_2 > n_3$ (B) $n_1 > n_3 > n_2$ (C) $n_2 > n_1 > n_3$ (D) $n_3 > n_1 > n_2$

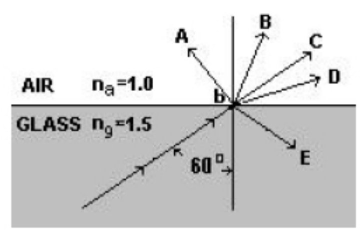


9. Which diagram best represents what happens to a ray of light entering air from water? Air is at the top in all diagrams.



10. In order to produce an enlarged, upright image of an object, you could use a
(A) converging lens more than one focal length from the object.
(B) converging lens less than one focal length from the object.
(C) diverging lens more than one focal length from the object.
(D) diverging lens exactly one focal length from the object..

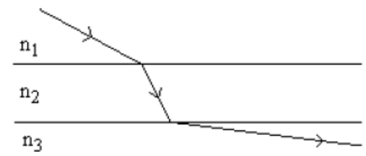
11. A beam of light traveling in glass (n_g = 1.5) strikes a boundary with air (n_a = 1.0) at point P. The angle of incidence is 60° as shown in the diagram. Which ray would best indicate the beam's path after point P?
(A) A (B) B (C) D (D) E



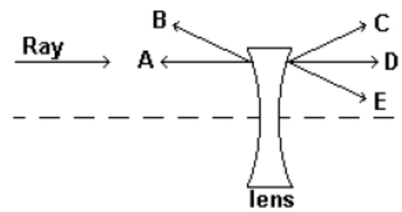
12. **Multiple Correct.** A small light bulb is placed 20 cm to the right of a converging lens of focal length 10 cm. Which of the following statements are true about the image of the bulb formed by the lens? Select two answers.
(A) It is virtual
(B) It is inverted
(C) It is one-half the size of the bulb
(D) It is 20 cm to the left of the lens

13. An image is formed on a screen by a convergent lens. If the top half of the lens is then covered what will happen to the image?
(A) the image is dimmer but otherwise unchanged
(B) the image becomes half as big
(C) only the top half of the image is produced
(D) only the bottom half of the image is produced

14. A beam of light passes from medium 1 to medium 2 to medium 3 as shown in the diagram. What may be concluded about the speed of light in each medium?
(A) $v_3 > v_1 > v_2$ (B) $v_1 > v_2 > v_3$ (C) $v_1 > v_3 < v_2$
(D) $v_2 > v_3 > v_1$



15. After striking the lens shown in the diagram at right, the light ray will most likely follow which path?
(A) path B B) path C C) path D D) path E

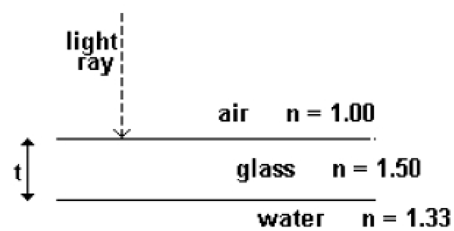


16. An object is placed 10 cm in front of the center of a concave curved mirror with a radius of curvature of 10 cm. About how far from the mirror will the real image of the object be formed?
(A) 0 cm (B) 5 cm (C) 10 cm (D) 20 cm

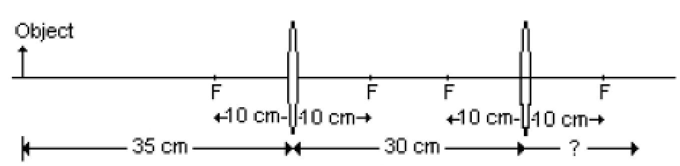
17. Light travels from material X with an index of refraction of n=1.5 to material Y with an index of refraction of n=2.0. If the speed of light in material Y is v, what is the speed of light in material X?
(A) 0.56 v (B) 0.75 v (C) 1.33 v (D) 1.78 v

18. A light ray is incident normal to a thin layer of glass. Given the figure, what is the minimum thickness of the glass that gives the reflected light an orange like color
(λ(air) orange light = 600nm)

(A) 50 nm (B) 100 nm (C) 150 nm (D) 200 nm



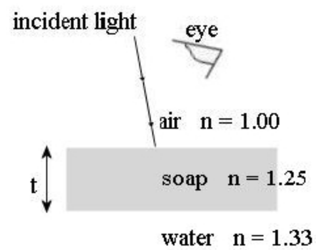
19. Two thin lenses each with a focal length of +10 cm are located 30 cm apart with their optical axes aligned as shown. An object is placed 35 cm from the first lens. After the light has passed through both lenses, at what distance from the second lens will the final image be formed?
(A) 65 cm (B) 35 cm (C) 27 cm (D) 17 cm



20. A converging lens forms a virtual image of a real object that is two times the objects size. The converging lens is replaced with a diverging lens having the same size focal length. What is the magnification of the image formed by the diverging lens?
(A) –1 (B) –2/5 (C) 2/3 (D) 3/2

21. An object is in front of a convex lens, at a distance less than the focal length from the lens. Its image is
(A) virtual and larger than the object.
(B) real and smaller than the object.
(C) virtual and smaller than the object.
(D) real and larger than the object.

22. Light is incident normal to a thin layer of soap. Given the figure, what is the minimum thickness of the soap film that gives the soap a blue like color (λ_{air}(blue) = 500 nm)?
(A) 100 nm (B) 200 nm (C) 250 nm (D) 400 nm



23. For which of the following does one obtain an image of increased size from a real object? Take all focus and radius of curvature values as positive.
(A) The object is placed at a position outside the radius of curvature for a converging lens.
(B) The object is placed at a position outside the radius of curvature for a diverging lens.
(C) The object is placed at a position inside the magnitude of the focus for a concave lens.
(D) The object is placed at a position between the focus and radius of curvature for a concave mirror.

24. A sound wave generated from a tuning fork of single frequency travels from air (with speed of sound 340 m/s) into rock (with speed of sound 1500 m/s). Which statement is true about the wavelength and frequency of the sound as it passes from air to rock?
A) The frequency of the sound increases and the wavelength increases.
B) The frequency of the sound increases and the wavelength is unchanged.
C) The frequency of the sound is unchanged and the wavelength is decreased.
D) The frequency of the sound is unchanged and the wavelength is increased.

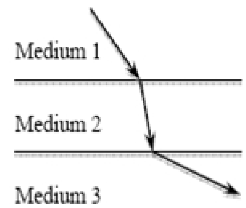
25. A diverging lens produces an image of a real object. This image is
(A) virtual, larger than the object, and upright.
(B) virtual, smaller than the object, and upright.
(C) virtual, smaller than the object, and inverted.
(D) real, smaller than the object, and inverted.

26. A light beam passes through the air and strikes the surface of a plastic block. Which pair of statements correctly describes the phase changes for the reflected wave and the transmitted wave?

	Reflected wave	Transmitted wave
(A)	90°	90°
(B)	No phase change	180°
(C)	No phase change	No phase change
(D)	180°	No phase change

27. **Multiple Correct.** The diagram below shows the path taken by a monochromatic light ray traveling through three media. The symbols v_1, λ_1, and f_1 represent the speed, wavelength, and frequency of the light in Medium 1, respectively. Which of the following relationships for the light in the three media is true? Select two answers:

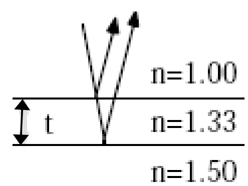
(A) $v_3 > v_1 > v_2$
(B) $f_1 = f_2 = f_3$
(C) $\lambda_1 > \lambda_2 > \lambda_3$
(D) $v_1 > v_2 > v_3$



28. A real object is located in front of a convex lens at a distance greater than the focal length of the lens. What type of image is formed and what is true of the image's size compared to that of the object?

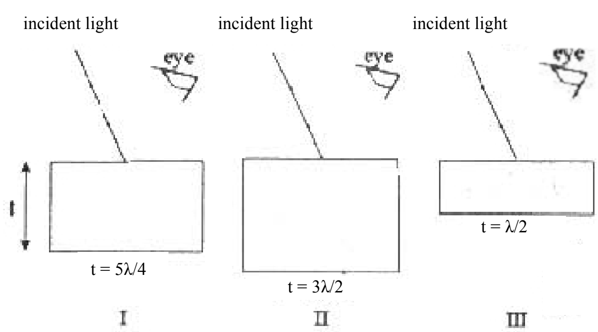
	Type of Image	Size of Image
(A)	Real	Larger than object
(B)	Real	More information is needed
(C)	Virtual	Smaller than object
(D)	Virtual	Larger than object

29. A thin film of thickness *t* and index of refraction 1.33 coats a glass with index of refraction 1.50 as shown to the right. Which of the following thicknesses *t* will not reflect light with wavelength 640 nm in air?
(A) 160 nm (B) 240 nm (C) 360 nm (D) 480 nm

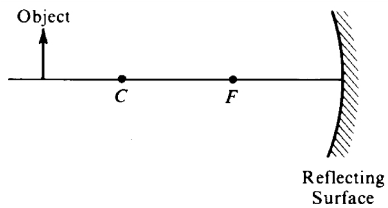


30. Lenses in fine quality cameras are coated to reduce the reflection from the lenses. If the coating material has an index of refraction between that of air and glass, what thickness of coating will produce the least reflection?
A) one–quarter of the wavelength in the coating
B) one–third of the wavelength in the coating
C) one–half of the wavelength in the coating
D) one wavelength in the coating

31. Light strikes three different thin films, which are in air, as shown. If *t* denotes the film thickness and λ denotes the wavelength of the light in the film, which films will produce constructive interference as seen by the observer?



(A) I only (B) II only (C) III only (D) II and III only



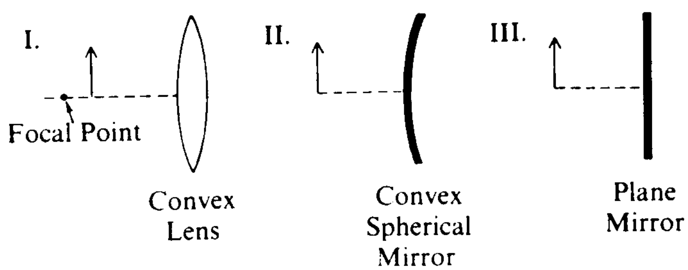
32. An object is placed as shown in the figure above. The center of curvature C and the focal point F of the reflecting surface are marked. As compared with the object, the image formed by the reflecting surface is
(A) erect and larger (B) erect and the same size (C) erect and smaller
(D) inverted and larger

33. When one uses a magnifying glass to read fine print, one uses a
(A) converging lens to produce a virtual image of the print
(B) converging lens to produce a real image of the print
(C) mirror to produce a virtual image of the print
(D) diverging lens to produce a real image of the print

34. An illuminated object is placed 0.30 meter from a lens whose focal length is –0.15 meter. The image is
(A) inverted, real, and 0.30 meter from the lens on the opposite side from the object
(B) upright, virtual, and 0.30 meter from the lens on the opposite side from the object
(C) upright, real, and 0.10 meter from the lens on the same side as the object
(D) upright, virtual, and 0.10 meter from the lens on the same side as the object

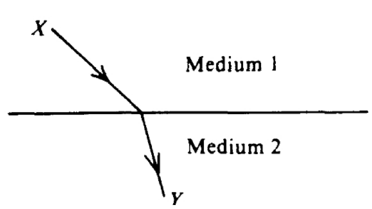
35. Which of the following CANNOT be accomplished by a single converging lens with spherical surfaces?
(A) Converting a spherical wave front into a plane wave front
(B) Converting a plane wave front into a spherical wave front
(C) Forming a virtual image of a real object
(D) Forming a real upright image of a real upright object

36. The image of the arrow is larger than the arrow itself in which of the following cases?

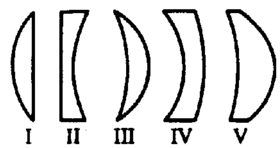


(A) I only (B) II only (C) I and III only (D) II and III only

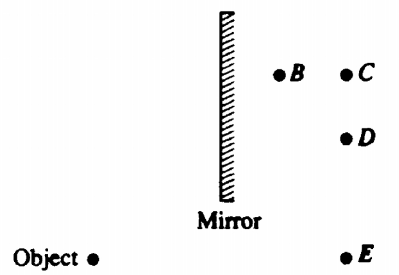
37. A postage stamp is placed 30 centimeters to the left of a converging lens of focal length 60 centimeters. Where is the image of the stamp located?
(A) 60 cm to the left of the lens (B) 20 cm to the left of the lens
(C) 20 cm to the right of the lens (D) 30 cm to the right of the lens



38. Light leaves a source at X and travels to Y along the path shown above. Which of the following statements is correct?
   (A) The index of refraction is the same for the two media.
   (B) Light travels faster in medium 2 than in medium 1.
   (C) Light would arrive at Y in less time by taking a straight line path from X to Y than it does taking the path shown above.
   (D) Light leaving a source at Y and traveling to X would follow the same path shown above, but in reverse.



39. Which three of the glass lenses above, when placed in air, will cause parallel rays of light to converge?
   (A) I, II, and III (B) I, III, and V (C) I, IV, and V (D) II, III, and IV



40. An object is placed near a plane mirror, as shown above. Which of the labeled points is the position of the image?
   (A) point B (B) point C (C) point D (D) point E

41. Observations that indicate that visible light has a wavelength much shorter than a centimeter include which of the following?
   I. The colored pattern seen in a soap bubble
   II. The colored pattern seen when light passes through a diffraction grating
   III. The bending of light when it passes from one medium to another medium
   (A) I only (B) III only (C) I and II only (D) II and III only

42. If the object distance for a converging thin lens is more than twice the focal length of the lens, the image is
   (A) virtual and erect (B) larger than the object (C) located inside the focal point (D) located at a distance between f and 2f from the lens

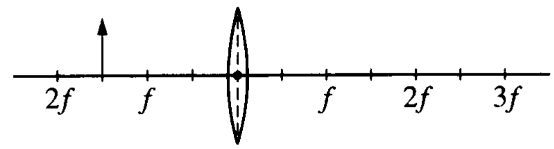
43. A concave mirror with a radius of curvature of 1.0 m is used to collect light from a distant star. The distance between the mirror and the image of the star is most nearly
   (A) 0.25 m (B) 0.50 m (C) 0.75 m (D) 1.0 m

44. When light passes from air into water, the frequency of the light remains the same. What happens to the speed and the wavelength of light as it crosses the boundary in going from air into water?

	Speed	Wavelength
(A)	Increases	Remains the same
(B)	Remains the same	Decreases
(C)	Remains the same	Remains the same
(D)	Decreases	Decreases

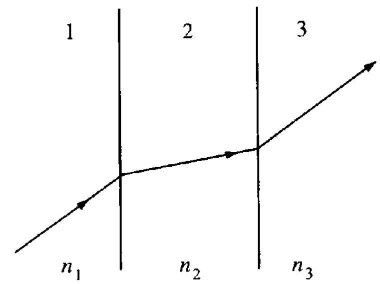
45. A physics student places an object 6.0 cm from a converging lens of focal length 9.0 cm. What is the magnitude of the magnification of the image produced?
(A) 0.6 (B) 1.5 (C) 2.0 (D) 3.0

46. An object is placed at a distance of 1.5f from a converging lens of focal length f, as shown. What type of image is formed and what is its size relative to the object?

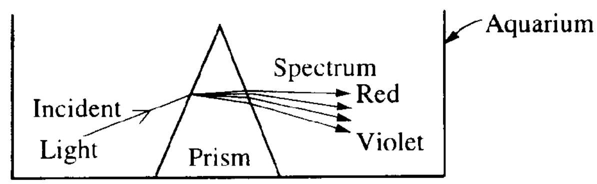


	Type	Size
(A)	Virtual	Larger
(B)	Virtual	Same size
(C)	Real	Smaller
(D)	Real	Larger

47. A light ray passes through substances 1, 2, and 3, as shown. The indices of refraction for these three substances are n_1, n_2, and n_3, respectively. Ray segments in 1 and 3 are parallel. From the directions of the ray, one can conclude that
(A) n_3 must be the same as n_1
(B) n_2 must be less than n_1
(C) n_2 must be less than n_3
(D all three indices must be the same



48. A beam of white light is incident on a triangular glass prism with an index of refraction of about 1.5 for visible light, producing a spectrum. Initially, the prism is in a glass aquarium filled with air, as shown above. If the aquarium is filled with water with an index of refraction of 1.3, which of the following is true?

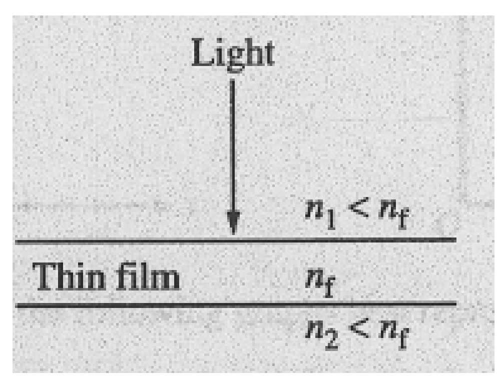


(A) A spectrum is produced, but the deviation of the beam is opposite to that in air.
(B) The positions of red and violet are reversed in the spectrum.
(C) The spectrum produced has greater separation between red and violet than that produced in air.
(D) The spectrum produced has less separation between red and violet than that produced in air.

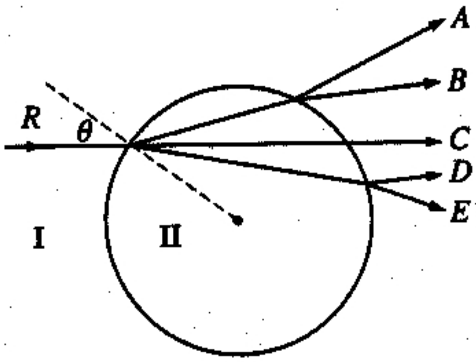
49. An object is placed in front of a converging thin lens at a distance from the center of the lens equal to half the focal length. Compared to the object, the image is
(A) upright and larger
(B) upright and smaller
(C) inverted and larger
(D) inverted and smaller

50. A thin film with index of refraction n_1 separates two materials, each of which has an index of refraction less than n_f. A monochromatic beam of light is incident normally on the film, as shown above. If the light has wavelength λ within the film, maximum constructive interference between the incident beam and the reflected beam occurs for which of the following film thicknesses?

(A) 2λ (B) λ (C) λ/2 (D) λ/4



Questions 51-52



A light ray R in medium I strikes a sphere of medium II with angle of incidence θ, as shown above. The figure shows five possible subsequent paths for the light ray.

51. Which path is possible if medium I is air and medium II is glass?
(A) path A (B) path C (C) path D (D) path E

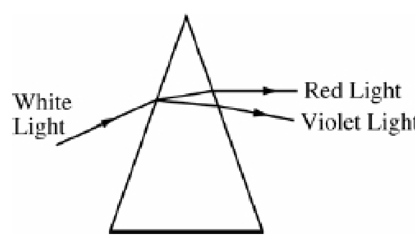
52. Which path is possible if medium I is glass and medium II is air?
(A) A (B) B (C) C (D) D

53. A large lens is used to focus an image of an object onto a screen. If the left half of the lens is covered with a dark card, which of the following occurs
(A) The left half of the image disappears
(B) The right half of the image disappears
(C) The image becomes blurred
(D) The image becomes dimmer

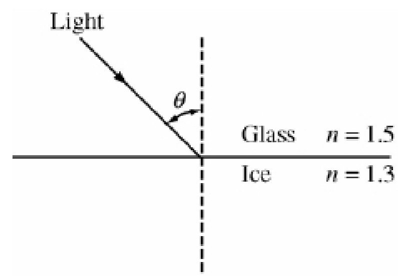
54. Which of the following statements are true for both sound waves and electromagnetic waves?
I. They can undergo refraction.
II. They can undergo diffraction.
III. They can produce a two-slit interference pattern.
IV. They can produce standing waves.

(A) I and II only (B) III and IV only (C) I, II, III and IV (D) II, III, and IV only

55. **Multiple Correct:** As shown, a beam of white light is separated into separate colors when it passes through a glass prism. Red light is refracted through a smaller angle than violet light because red light has a: Select two answers.
(A) slower speed in glass than violet light
(B) faster speed in glass than violet light
(C) slower speed in the incident beam than violet light
(D) lower index of refraction in glass than violet light



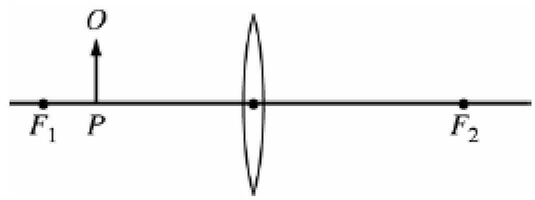
56. A ray of light in glass that is incident on an interface with ice, as shown, is partially reflected and partially refracted. The index of refraction n for each of the two media is given in the figure. How do the angle of reflection and the angle of refraction compare with the angle of incidence θ ?



	Angle of Reflection	Angle of Refraction
(A)	Same	Larger
(B)	Same	Smaller
(C)	Smaller	Same
(D)	Smaller	Smaller

Questions 57-58:

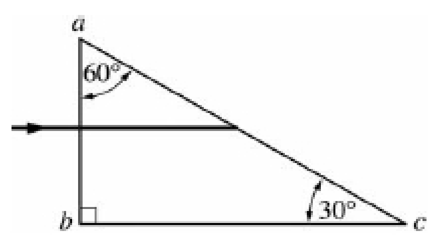
An object O is located at point P to the left of a converging lens, as shown in the figure. F_1 and F_2 are the focal points of the lens.



57. If the focal length of the lens is 0.40 m and point P is 0.30 m to the left of the lens, where is the image of the object located?
(A) 1.2 m to the left of the lens
(B) 0.17 m to the left of the lens
(C) At the lens
(D) 0.17 m to the right of the lens

58. Which of the following characterizes the image when the object is in the position shown?
(A) Real, inverted, and smaller than the object
(B) Real, upright, and larger than the object
(C) Real, inverted, and larger than the object
(D) Virtual, upright, and larger than the object

59. A ray of light in air is incident on a 30-°60°-90° prism, perpendicular to face *ab*, as shown in the diagram. The ray enters the prism and strikes face *ac* at the critical angle. What is the index of refraction of the prism?



$A)\ \frac{1}{2}$ $\quad B)\ \sqrt{\frac{3}{2}}$ $\quad C)\ \frac{2\sqrt{3}}{3}$ $\quad D)\ 2$

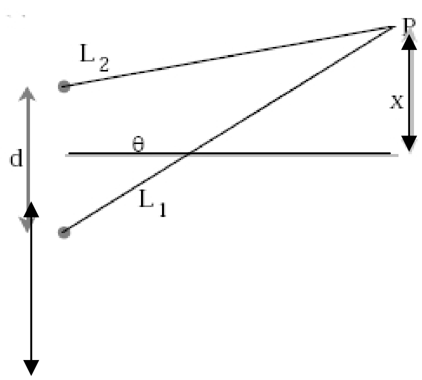
SECTION B – Physical Optics

1. In Young's double slit experiment, the second order bright band of one light source overlaps the third order band of another light source. If the first light source has a wavelength of 660 nm, what is the wavelength of the second light source?
A) 1320 nm B) 990 nm C) 440 nm D) 330 nm

2. A diffraction grating of 1000 lines/cm has red light of wavelength 700 nm pass through it. The distance between the first and third principal bright spots on a screen 2 m away is
A) 14 cm B) 28 cm C) 42 cm D) 140 cm

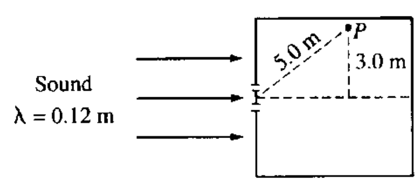
3. In a Young's double-slit experiment, the slit separation is doubled. To maintain the same fringe spacing on the screen, the screen-to-slit distance D must be changed to
A) $D/2$ B) $\frac{D}{\sqrt{2}}$ C) $\sqrt{2}D$ D) $2D$

4. Two sources, in phase and a distance d apart, each emit a wave of wavelength λ. See figure below. Which of the choices for the path difference $\Delta L = L_1 - L_2$ will *always* produce destructive interference at point P?
A) d sin θ B) $(x/L_2)d$ C) λ/2 D) 2 λ



5. In an experiment to measure the wavelength of light using a double slit apparatus, it is found that the bright fringes are too close together to easily count them. To increase only the spacing between the bright fringes, one could
A) increase the slit width
B) decrease the slit width
C) increase the slit separation
D) decrease the slit separation

6. Plane sound waves of wavelength 0.12 m are incident on two narrow slits in a box with nonreflecting walls, as shown. At a distance of 5.0 m from the center of the slits, a first-order maximum occurs at point *P*, which is 3.0 m from the central maximum. The distance between the slits is most nearly



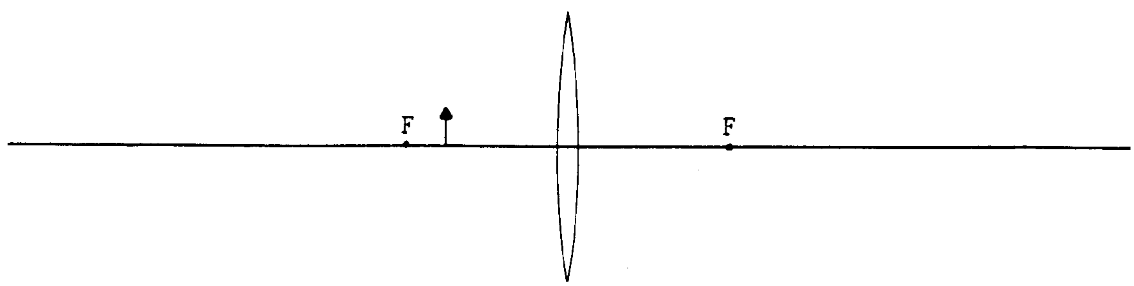
(A) 0.09 m (B) 0.16 m (C) 0.20 m (D) 0.24 m

7. If one of the two slits in a Young's double-slit demonstration of the interference of light is covered with a thin filter that transmits only half the light intensity, which of the following occurs?
(A) The bright lines are brighter and the dark lines are darker.
(B) The bright lines and the dark lines are all darker.
(C) The bright lines and the dark lines are all brighter.
(D) The dark lines are brighter and the bright lines are darker.

SECTION A – Geometric Optics

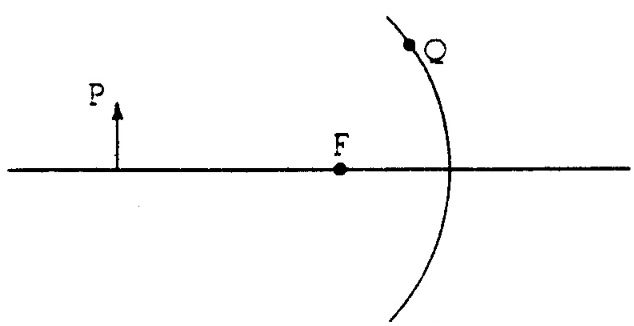
1974B3. An object 1 centimeter high is placed 4 centimeters away from a converging lens having a focal length of 3 centimeters.

(a) Sketch a principal ray diagram for this situation.
(b) Find the location of the image by a numerical calculation.
(c) Determine the size of the image.



1976B6. An object of height 1 centimeter is placed 6 centimeters to the left of a converging lens whose focal length is 8 centimeters, as shown on the diagram above.

(a) Calculate the position of the image. Is it to the left or right of the lens? Is it real or virtual?
(b) Calculate the size of the image. Is it upright or inverted?
(c) On the diagram, locate the image by ray tracing.
(d) What simple optical instrument uses this sort of object-image relationship?



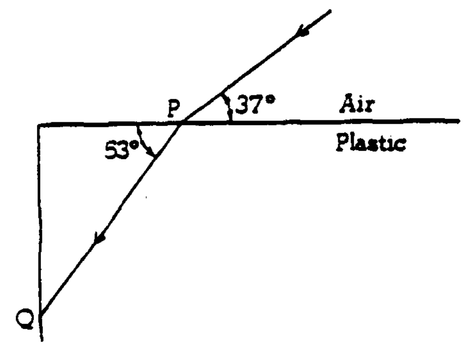
1978B5. An object 6 centimeters high is placed 30 centimeters from a concave mirror of focal length 10 centimeters as shown above.

(a) On the diagram above, locate the image by tracing two rays that begin at point P and pass through the focal point F. Is the image real or virtual? Is it located to the left or to the right of the mirror?
(b) Calculate the position of the image.
(c) Calculate the size of the image.
(d) Indicate on the diagram above how the ray from point P to point Q is reflected, if aberrations are negligible.

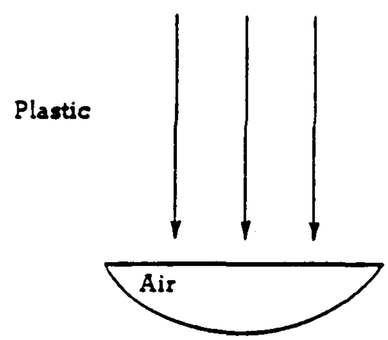
1979B6. A light ray enters a block of plastic and travels along the path shown.

a. By considering the behavior of the ray at point P, determine the speed of light in the plastic.

b. Determine what will happen to the light ray when it reaches point Q, using the diagram to illustrate your conclusion.

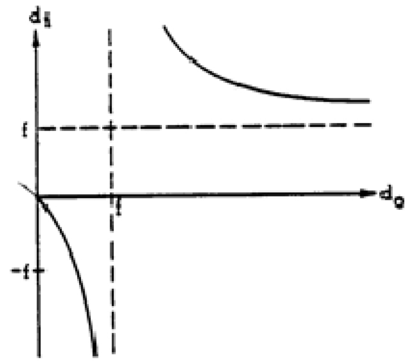


c. There is an air bubble in the plastic block that happens to be shaped like a plano-convex lens as shown below. Sketch what happens to parallel rays of light that strike this air bubble. Explain your reasoning.



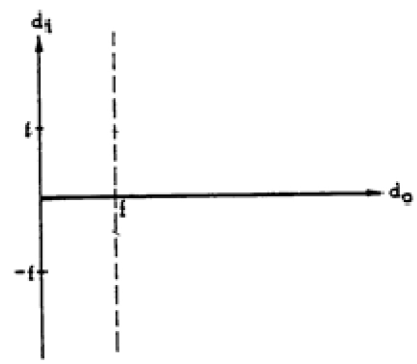
1980B4. In the graphs that follow, a curve is drawn in the first graph of each pair. For the other graph in each pair, sketch the curve showing the relationship between the quantities labeled on the axes. Your graph should be consistent with the first graph in the pair.

(e) d_i = Image Distance (positive to right of lens) for a Thin Convex (converging) Lens of Focal Length f



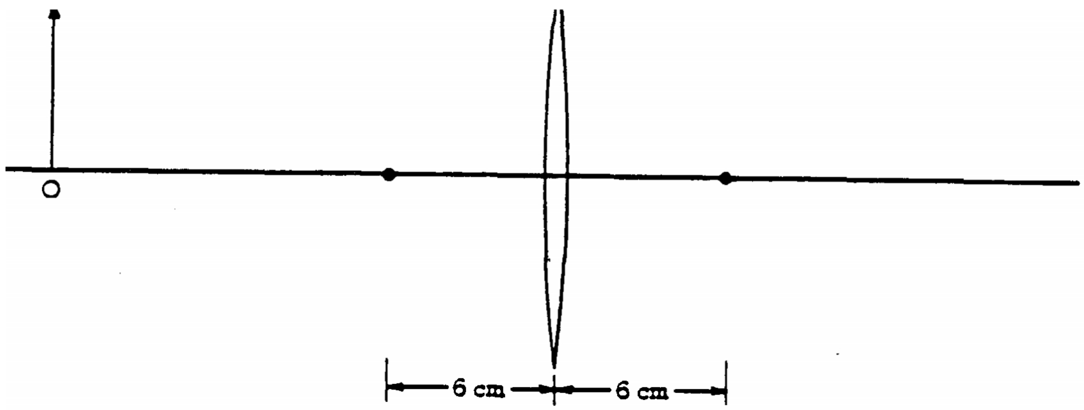
d_o = Object Distance (positive to left of lens) for the Same Lens

d_i = Image Distance (positive to right of lens) for a Thin Concave (diverging) Lens of Focal Length $-f$



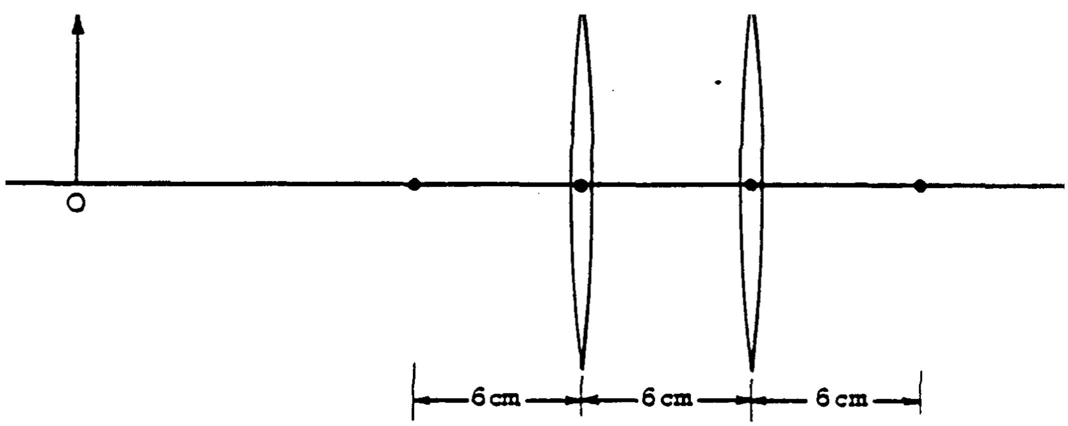
d_o = Object Distance (positive to left of lens) for the Same Lens

1981B5. An object O is placed 18 centimeters from the center of a converging lens of focal length 6 centimeters as illustrated below:



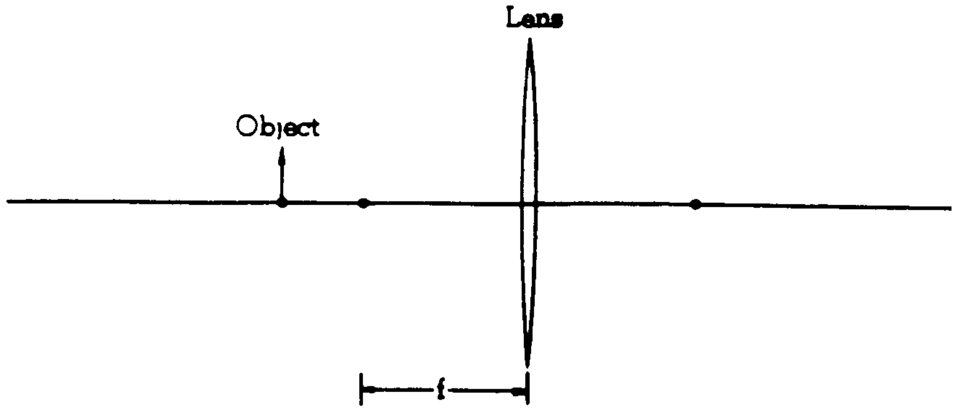
a. On the illustration above, sketch a ray diagram to locate the image.
b. Is the Image real or virtual? Explain your choice.
c. Using the lens equation, compute the distance of the image from the lens.

A second converging lens, also of focal length 6 centimeters is placed 6 centimeters to the right of the original lens as illustrated below.



d. On the illustration above, sketch a ray diagram to locate the final image that now will be formed. Clearly indicate the final image.

1982B6. An object is located a distance 3f/2 from a thin converging lens of focal length f as shown in the diagram below.



a. Calculate the position of the image.
b. Trace two of the principal rays to verify the position of the image.
c. Suppose the object remains fixed and the lens is removed. Another converging lens of focal length f_2 is placed in exactly the same position as the first lens. A new real image larger than the first is now formed. Must the focal length of the second lens be greater or less than f ? Justify your answer

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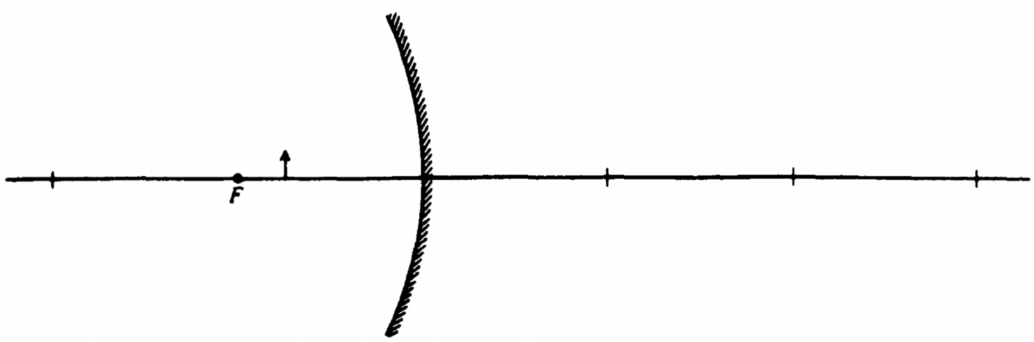
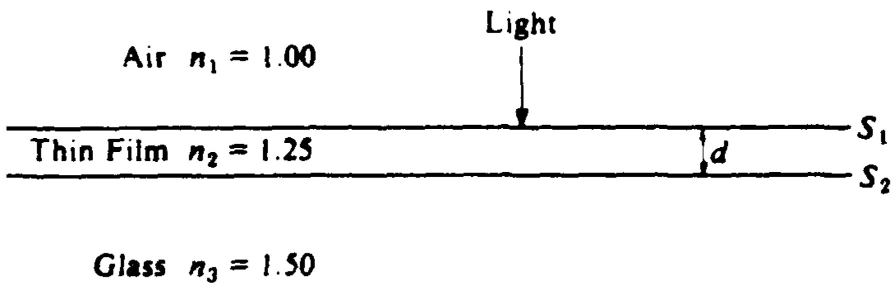


1983B5. The concave mirror shown above has a focal length of 20 centimeters. An object 3 centimeter high is placed 15 centimeters in front of the mirror.
a. Using at least two principal rays, locate the image on the diagram above.
b. Is the image real or virtual? Justify your answer.
c. Calculate the distance of the image from the mirror.
d. Calculate the height of the image.

1984B5. The surface of a glass plate (index of refraction n_3 = 1.50) is coated with a transparent thin film (index of refraction n_2 = 1.25). A beam of monochromatic light of wavelength 6.0 x 10^{-7} meter traveling in air (index of refraction n_1 = 1.00) is incident normally on surface S_1 as shown. The beam is partially transmitted and partially reflected.



a. Calculate the frequency of the light.
b. Calculate the wavelength of the light in the thin film.

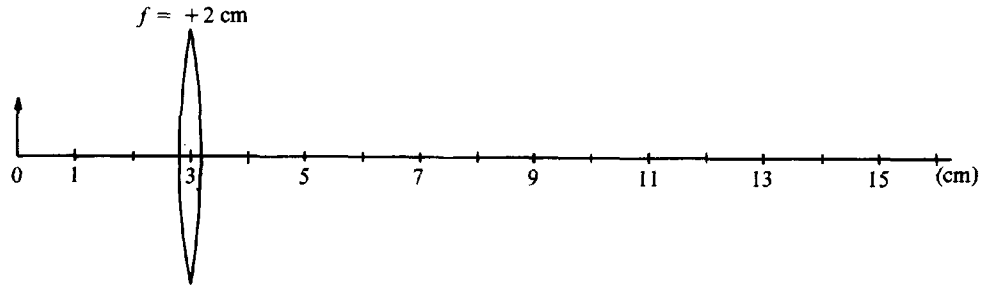
The beam of light in the film is then partially reflected and partially transmitted at surface S_2
c. Calculate the minimum thickness d_1 of the film such that the resultant intensity of the light reflected back into the air is a minimum.
d. Calculate the minimum nonzero thickness d_2 of the film such that the resultant intensity of the light reflected back into the air is a maximum.

NOTE: This is a repeat from the physical optics section but has an important new part in it in bold.

1985B5. Light of wavelength 5.0 x 10^{-7} meter in air is incident normally (perpendicularly) on a double slit. The distance between the slits is 4.0 x 10^{-4} meter, and the width of each slit is negligible. Bright and dark fringes are observed on a screen 2.0 meters away from the slits.
a. Calculate the distance between two adjacent bright fringes on the screen.

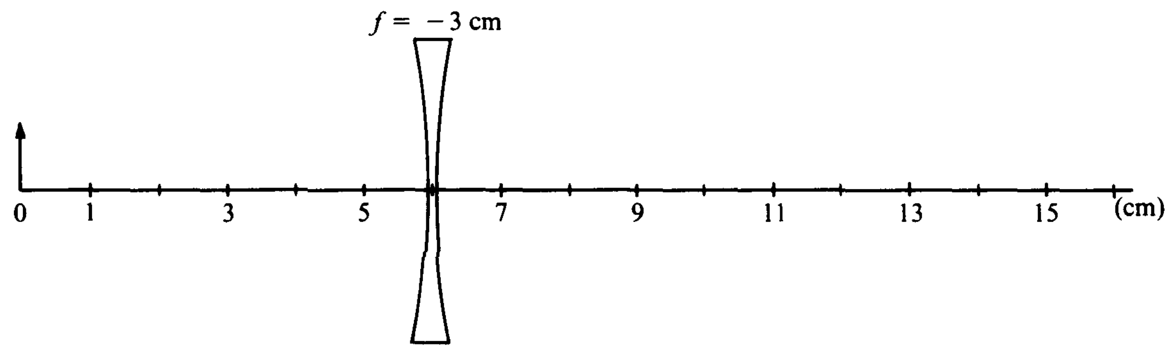
The entire double-slit apparatus, including the slits and the screen, is submerged in water, which has an index of refraction 1.3.
b. Determine each of the following for this light in water.
i. The wavelength
ii. The frequency
c. State whether the distance between the fringes on the screen increases, decreases, or remains the same. Justify your answer.

1986B6. An object is placed 3 centimeters to the left of a convex (converging) lens of focal length f = 2 cm, as shown below.



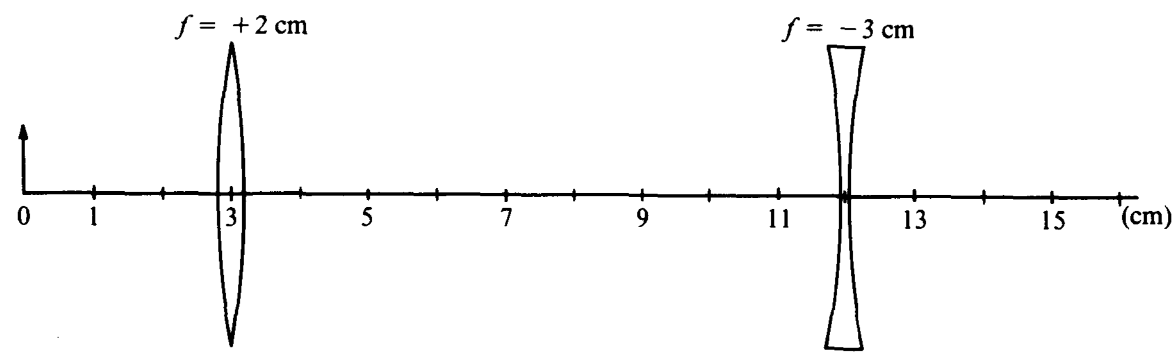
a. Sketch a ray diagram on the figure above to construct the image. It may be helpful to use a straightedge.
b. Determine the ratio of image size to object size.

The converging lens is removed and a concave (diverging) lens of focal length f = –3 centimeters is placed as shown below.



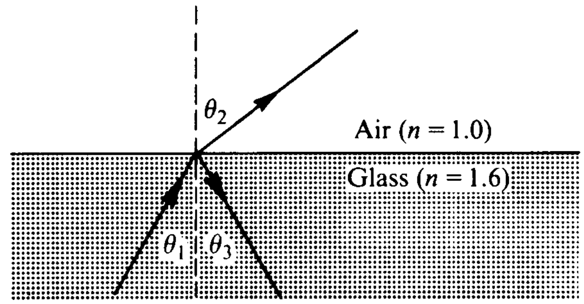
c. Sketch a ray diagram on the figure above to construct the image.
d. Calculate the distance of this image from the lens.
e. State whether the image is real or virtual.

The two lenses and the object are then placed as shown below.



f. Construct a complete ray diagram to show the final position of the image produced by the two-lens system.

1987B5. Light of frequency 6.0 x 10^{14} hertz strikes a glass/air boundary at an angle of incidence θ_1. The ray is partially reflected and partially refracted at the boundary, as shown. The index of refraction of this glass is 1.6 for light of this frequency.



a. Determine the value of θ_3 if $\theta_1 = 30°$.
b. Determine the value of θ_2 if $\theta_1 = 30°$.
c. Determine the speed of this light in the glass.
d. Determine the wavelength of this light in the glass.
e. What is the largest value of θ_1 that will result in a refracted ray?

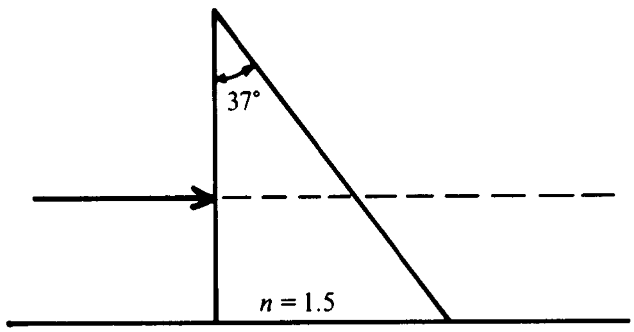


Figure I

1988B5. The triangular prism shown in Figure I above has index of refraction 1.5 and angles of 37°, 53°, and 90°. The shortest side of the prism is set on a horizontal table. A beam of light, initially horizontal, is incident on the prism from the left.

a. On Figure I above, sketch the path of the beam as it passes through and emerges from the prism.
b. Determine the angle with respect to the horizontal (angle of deviation) of the beam as it emerges from the prism.
c. The prism is replaced by a new prism of the same shape, which is set in the same position. The beam experiences total internal reflection at the right surface of this prism. What is the minimum possible index of refraction of this prism?

The new prism having the index of refraction found in part (c) is then completely submerged in water (index of refraction = 1.33) as shown in Figure II below. A horizontal beam of light is again incident from the left.

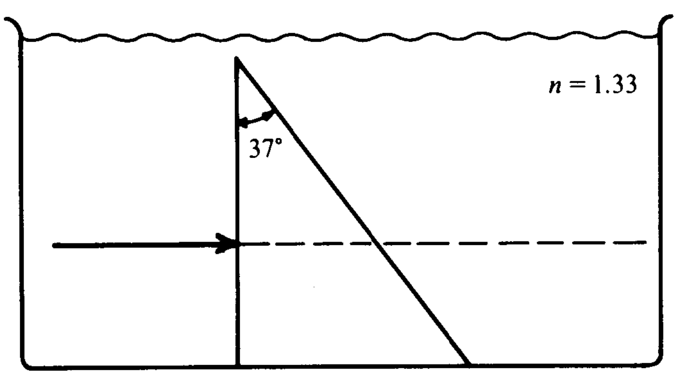
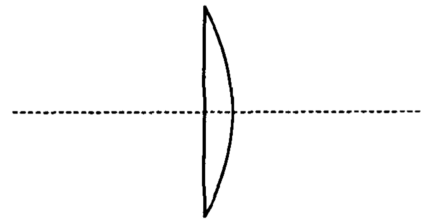


Figure II

d. On Figure II, sketch the path of the beam as it passes through and emerges from the prism.
e. Determine the angle with respect to the horizontal (angle of deviation) of the beam as it emerges from the prism.



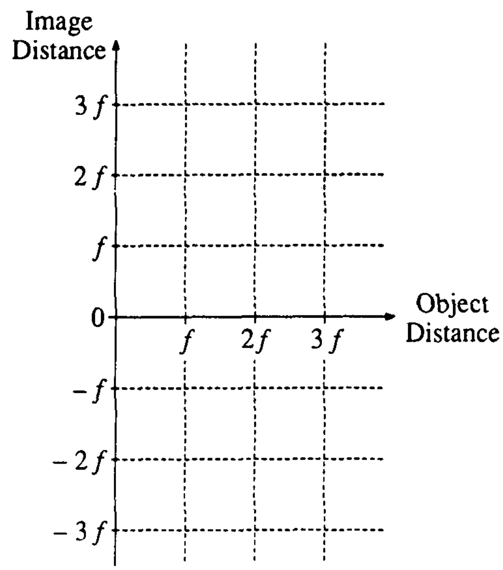
1989B5. The plano-convex lens shown above has a focal length f of 20 centimeters in air. An object is placed 60 centimeters (3f) from this lens.

a. State whether the image is real or virtual.

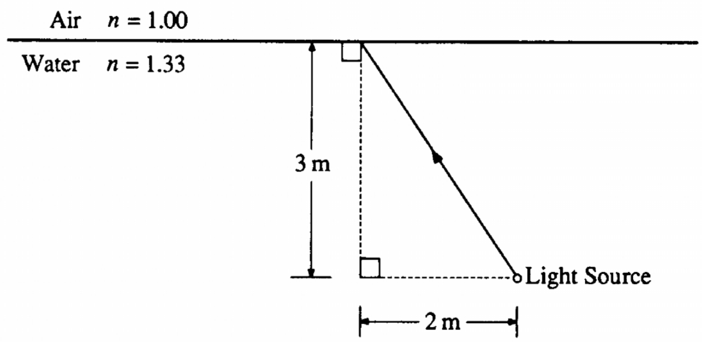
b. Determine the distance from the lens to the image.

c. Determine the magnification of this image (ratio of image size to object size).

d. The object, initially at a distance 3f from the lens, is moved toward the lens. On the axes below, sketch the image distance as the object distance varies from 3f to zero.

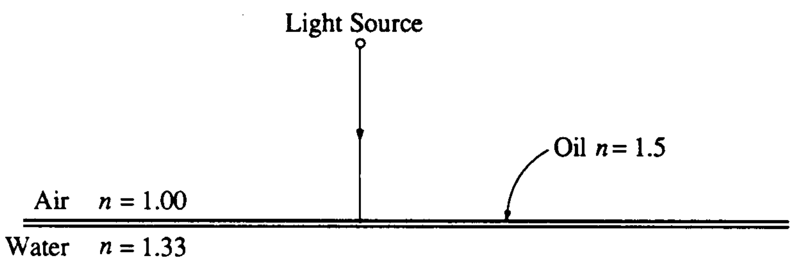


e. State whether the focal length of the lens would increase, decrease, or remain the same if the index of refraction of the lens were increased. Explain your reasoning.



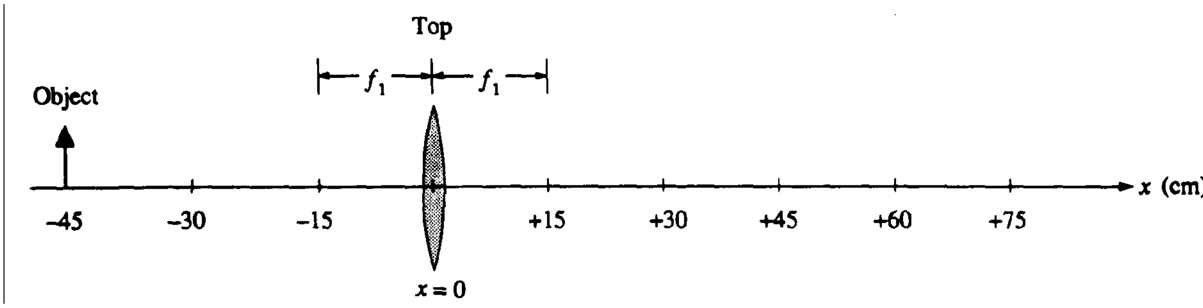
1990B6. A beam of light from a light source on the bottom of a swimming pool 3.0 meters deep strikes the surface of the water 2.0 meters to the left of the light source, as shown above. The index of refraction of the water in the pool is 1.33.

a. What angle does the reflected ray make with the normal to the surface?
b. What angle does the emerging ray make with the normal to the surface?
c. What is the minimum depth of water for which the light that strikes the surface of the water 2.0 meters to the left of the light source will be refracted into the air?



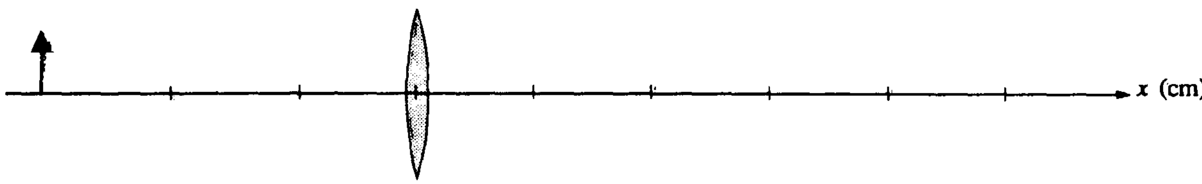
In one section of the pool, there is a thin film of oil on the surface of the water. The thickness of the film is 1.0×10^{-7} meter and the index of refraction of the oil is 1.5. The light source is now held in the air and illuminates the film at normal incidence, as shown above.

d. At which of the interfaces (air-oil and oil-water), if either, does the light undergo a 180° phase change upon reflection?
e. For what wavelengths in the visible spectrum will the intensity be a maximum in the reflected beam?



1992B6. A thin double convex lens of focal length f, = + 15 centimeters is located at the origin of the x-axis, as shown above. An object of height 8 centimeters is placed 45 centimeters to the left of the lens.

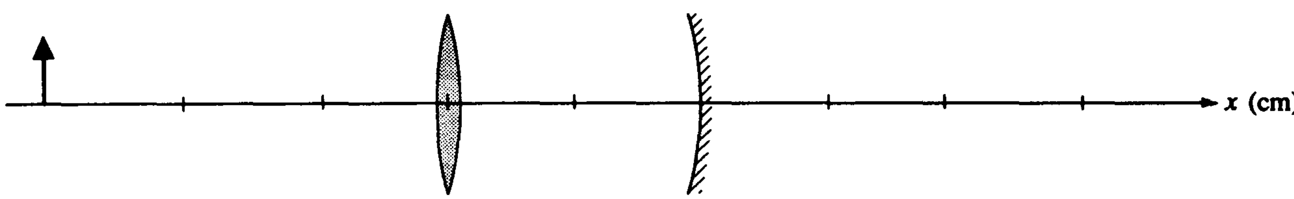
a. On the figure below, draw a ray diagram to show the formation of the image by the lens. Clearly show principal rays.



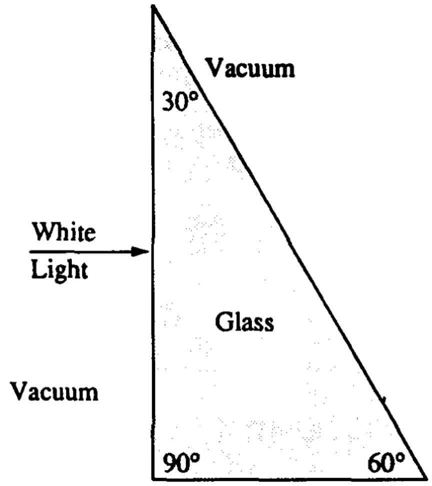
b. Calculate (do not measure) each of the following.
   i. The position of the image formed by the lens
   ii. The size of the image formed by the lens
c. Describe briefly what would happen to the image formed by the lens if the top half of the lens were blocked so that no light could pass through.

A concave mirror with focal length f_2 = + 15 centimeters is placed at x = + 30 centimeters.

d. On the figure below, indicate the position of the image formed by the lens, and draw a ray diagram to show the formation of the image by the mirror. Clearly show principal rays.



	Wavelength in Vacuum	Index of Refraction of Glass
Red Light	700 nm	1.5
Blue Light	480 nm	1.6



1993B4. The glass prism shown above has an index of refraction that depends on the wavelength of the light that enters it. The index of refraction is 1.50 for red light of wavelength 700 nanometers (700 x 10^{-9} meter) in vacuum and 1.60 for blue light of wavelength 480 nanometers in vacuum. A beam of white light is incident from the left, perpendicular to the first surface, as shown in the figure, and is dispersed by the prism into its spectral components.

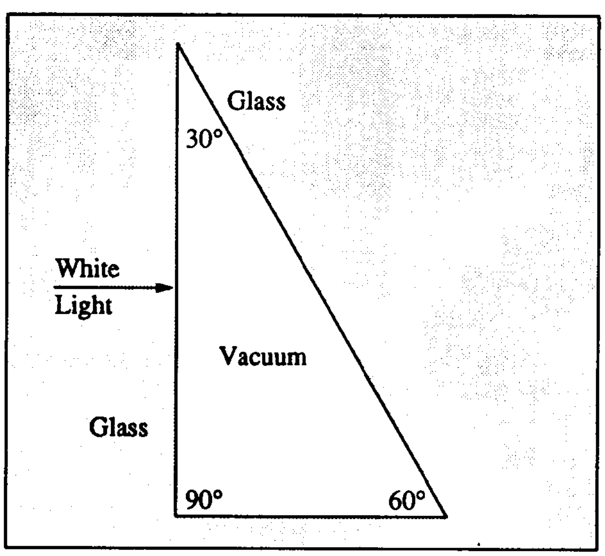
a. Determine the speed of the blue light in the glass.

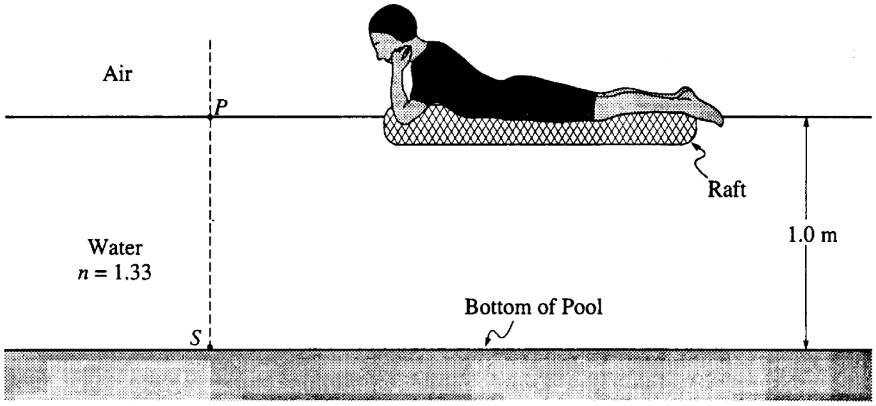
b. Determine the wavelength of the red light in the glass.

c. Determine the frequency of the red light in the glass.

d. On the figure above, sketch the approximate paths of both the red and the blue rays as they pass through the glass and back out into the vacuum. Ignore any reflected light. It is not necessary to calculate any angles, but do clearly show the change in direction of the rays, if any, at each surface and be sure to distinguish carefully any differences between the paths of the red and the blue beams.

e. The figure below represents a wedge-shaped hollow space in a large piece of the type of glass described above. On this figure, sketch the approximate path of the red and the blue rays as they pass through the hollow prism and back into the glass. Again, ignore any reflected light, clearly show changes in direction, if any, where refraction occurs, and carefully distinguish any differences in the two paths.





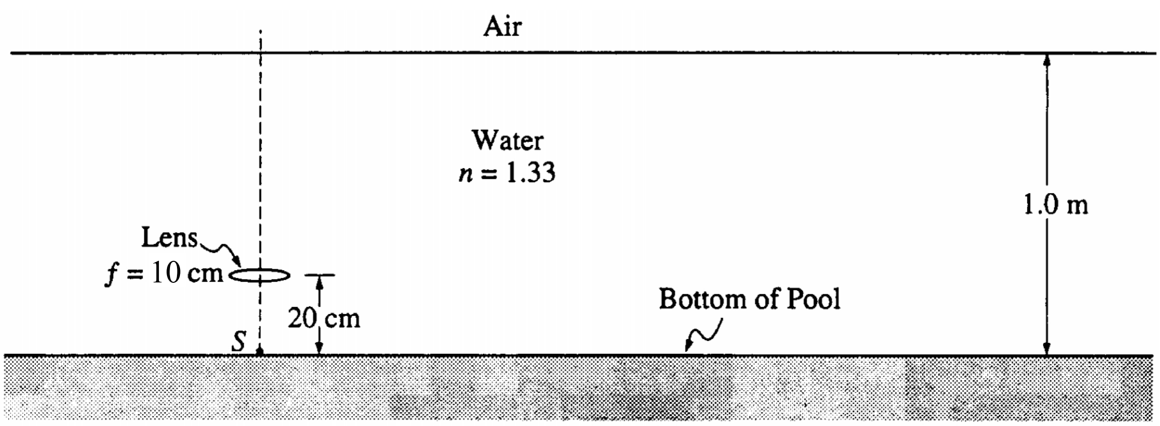
1994B5. A point source S of monochromatic light is located on the bottom of a swimming pool filled with water to a depth of 1.0 meter, as shown above. The index of refraction of water is 1.33 for this light. Point P is located on the surface of the water directly above the light source. A person floats motionless on a raft so that the surface of the water is undisturbed.

a. Determine the velocity of the source's light in water.

b. On the diagram above, draw the approximate path of a ray of light from the source S to the eye of the person. It is not necessary to calculate any angles.

c. Determine the critical angle for the air-water interface.

Suppose that a converging lens with focal length 10 centimeters in water is placed 20 centimeters above the light source, as shown in the diagram below. An image of the light source is formed by the lens.



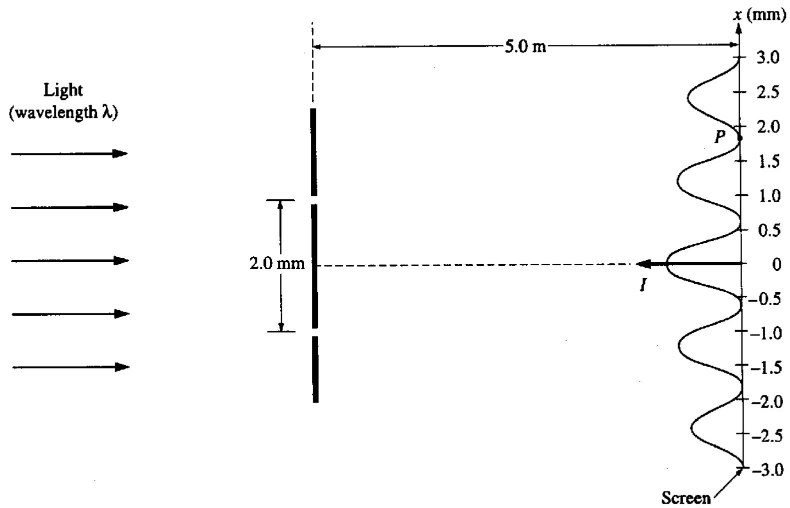
d. Calculate the position of the image with respect to the bottom of the pool.

e. If, instead, the pool were filled with a material with a different index of refraction, describe the effect, if any, on the image and its position in each of the following cases.

i. The index of refraction of the material is equal to that of the lens.

ii. The index of refraction of the material is greater than that of water but less than that of the lens.

NOTE: This is a repeat from the physical optics section but has an important new part in it in bold.



1996B3. Coherent monochromatic light of wavelength λ in air is incident on two narrow slits, the centers of which are 2.0 mm apart, as shown above. The interference pattern observed on a screen 5.0 m away is represented in the figure by the graph of light intensity I as a function of position x on the screen.

a. What property of light does this interference experiment demonstrate?

b. At point P in the diagram, there is a minimum in the interference pattern. Determine the path difference between the light arriving at this point from the two slits.

c. Determine the wavelength, λ, of the light.

d. Briefly and qualitatively describe how the interference pattern would change under each of the following separate modifications and explain your reasoning.

   i. The experiment is performed in water, which has an index of refraction greater than 1.

   ii. One of the slits is covered.

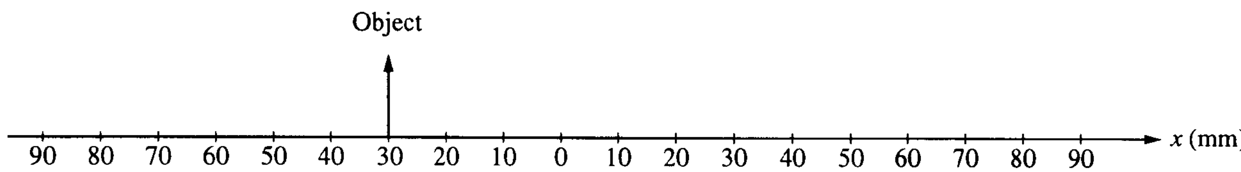
   iii. The slits are moved farther apart.

1997B5. An object is placed 30 mm in front of a lens located at x = 0. An image of the object is located 90 mm behind the lens.

a. Is the lens converging or diverging? Explain your reasoning.

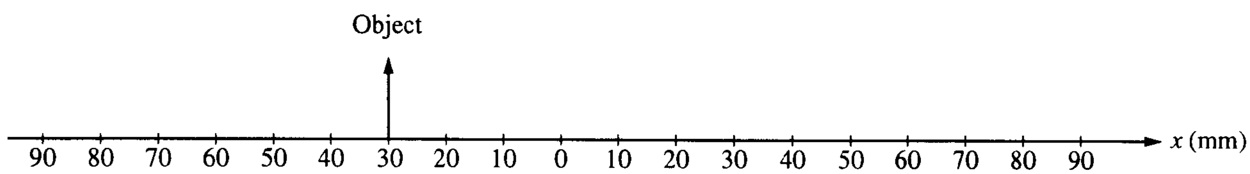
b. What is the focal length of the lens?

c. On the axis below, draw the lens at position x = 0. Draw at least two rays and locate the image to show the situation described above.



d. Based on your diagram in (c), describe the image by answering the following questions in the blank spaces provided.
Is the image real or virtual?__________________
Is the image smaller than, larger than, or same size as the object?_________________
Is the image inverted or upright compared to the object?_________________

e. The lens is replaced by a concave mirror of focal length 20 mm. On the axis below, draw the mirror at position x = 0 so that a real image is formed. Draw at least two rays and locate the image to show this situation



1999B6. You are given the following equipment for use in the optics experiments in parts (a) and (b).

A solid rectangular block made of transparent plastic
A laser that produces a narrow, bright, monochromatic ray of light
A protractor
A meterstick
A diffraction grating of known slit spacing
A white opaque screen

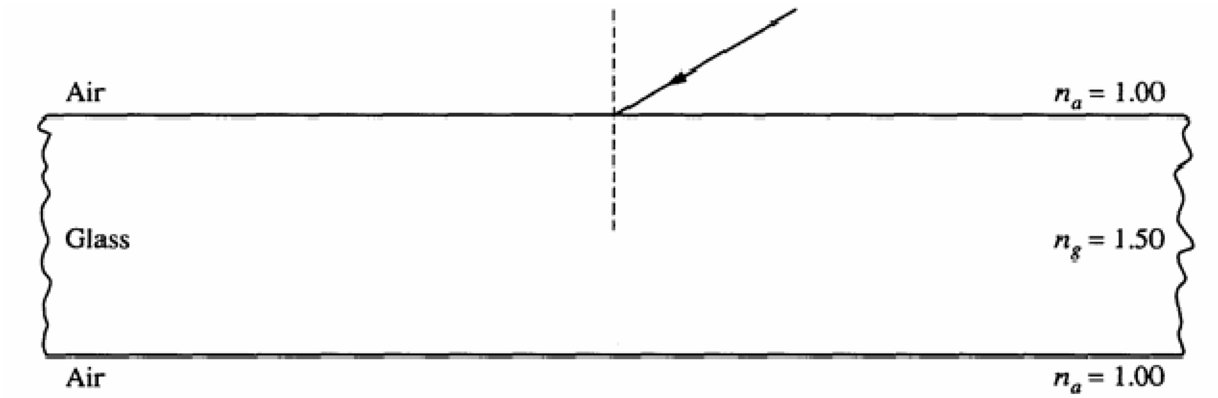
a. Briefly describe the procedure you would use to determine the index of refraction of the plastic. Include a labeled diagram to show the experimental setup. Write down the corresponding equation you would use in your calculation and make sure all the variables in this equation are labeled on your diagram.

b. Since the index of refraction depends on wavelength, you decide you also want to determine the wavelength of your light source. Draw and label a diagram showing the experimental setup. Show the equation(s) you would use in your calculation and identify all the variables in the equation(s). State and justify any assumptions you make.

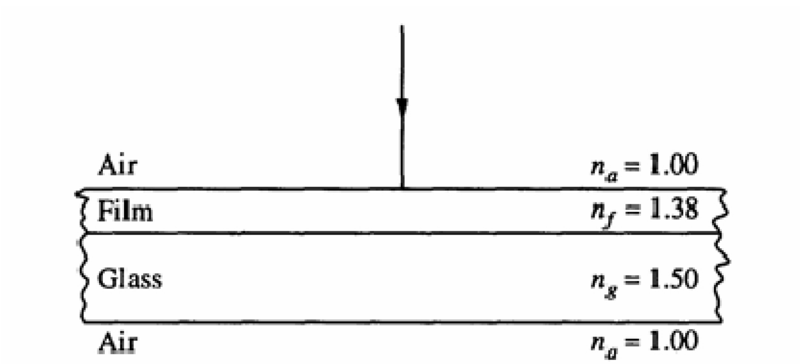
2000B4.

A sheet of glass has an index of refraction $n_g = 1.50$. Assume that the index of refraction for air is $n_a = 1.00$.

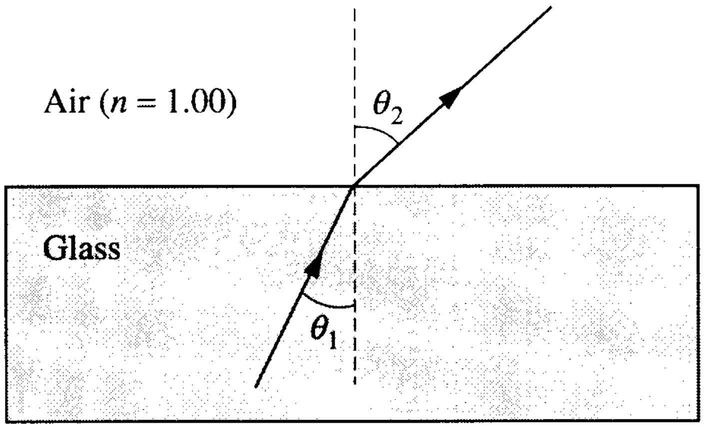
a. Monochromatic light is incident on the glass sheet, as shown in the figure below, at an angle of incidence of 60°. On the figure, sketch the path the light takes the first time it strikes each of the two parallel surfaces. Calculate and label the size of each angle (in degrees) on the figure, including angles of incidence, reflection, and refraction at each of the two parallel surfaces shown.



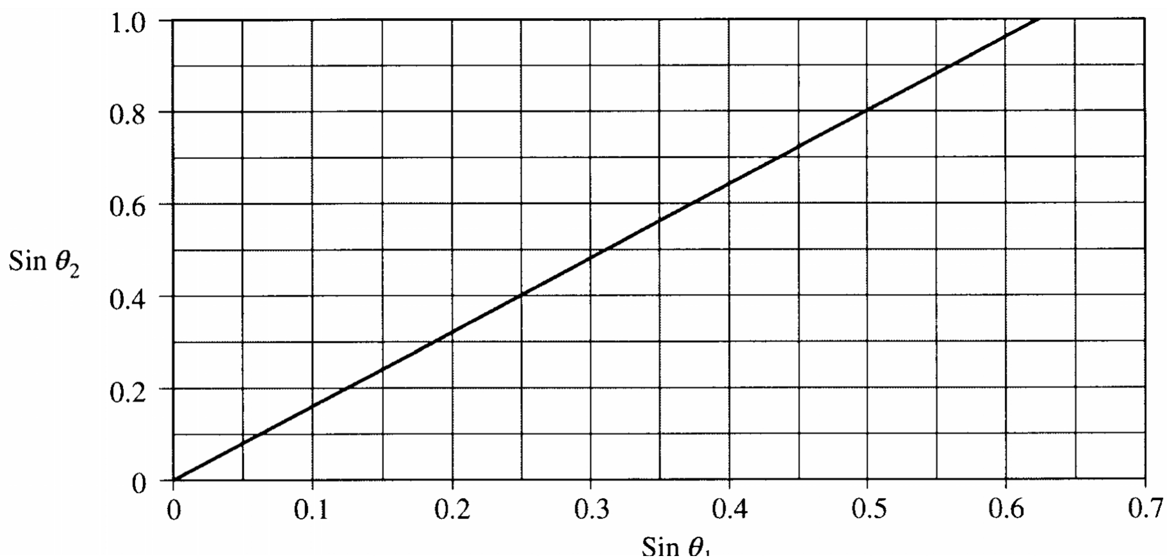
b. Next a thin film of material is to be tested on the glass sheet for use in making reflective coatings. The film has an index of refraction $n_f = 1.38$. White light is incident normal to the surface of the film as shown below. It is observed that at a point where the light is incident on the film, light reflected from the surface appears green (λ = 525 nm).



i. What is the frequency of the green light in air?
ii. What is the frequency of the green light in the film?
iii. What is the wavelength of the green light in the film?
iv. Calculate the minimum thickness of film that would produce this green reflection.



2001B4. In an experiment, a beam of red light of wavelength 675 nm (in air), passes from glass into air, as shown above. The incident and refracted angles are θ_1 and θ_2 , respectively. In the experiment, angle θ_2 is measured for various angles of incidence θ_1, and the sines of the angles are used to obtain the line shown in the following graph.



a. Assuming an index of refraction of 1.00 for air, use the graph to determine a value for the index of refraction of the glass for the red light. Explain how you obtained this value.

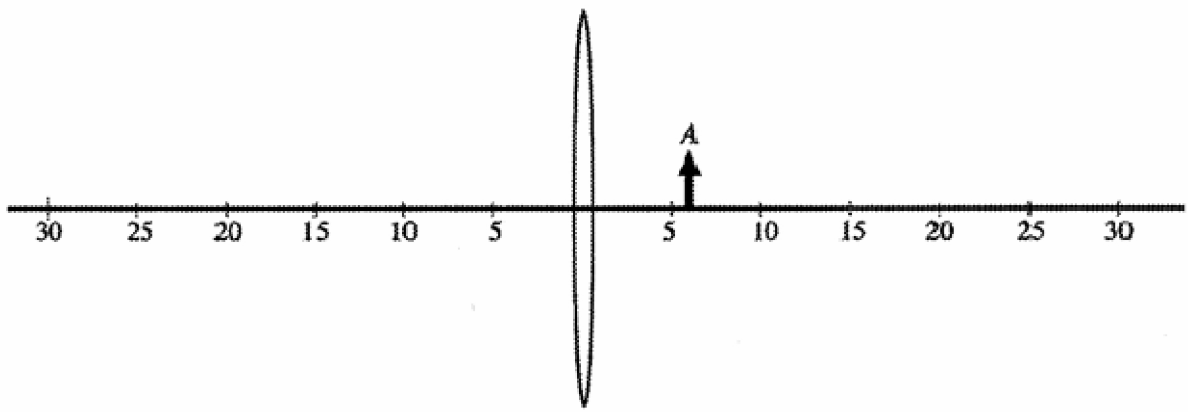
b. For this red light, determine the following.
   i. The frequency in air
   ii. The speed in glass
   iii. The wavelength in glass

c. The index of refraction of this glass is 1.66 for violet light, which has wavelength 425 nm in air.
   i. Given the same incident angle θ_1, show on the ray diagram at the top of the page how the refracted ray for the violet light would vary from the refracted ray already drawn for the red light.
   ii. Sketch the graph of sin θ_2 versus sin θ_1 for the violet light on the figure above that shows the same graph already drawn for the red light.

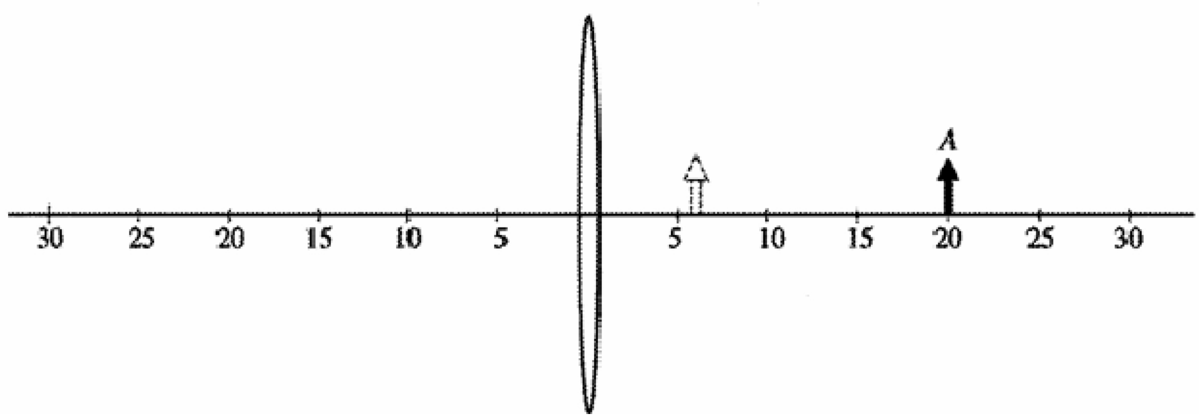
d. Determine the critical angle of incidence θ_c, for the violet light in the glass in order for total internal reflection to occur.

2002B4. A thin converging lens of focal length 10 cm is used as a simple magnifier to examine an object *A* that is held 6 cm from the lens.

(a) On the figure below, draw a ray diagram showing the position and size of the image formed.

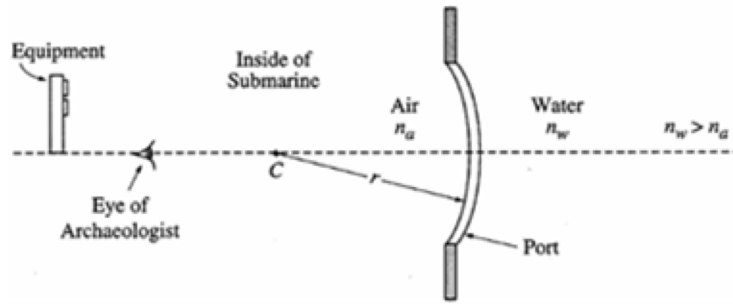


(b) State whether the image is real or virtual. Explain your reasoning.
(c) Calculate the distance of the image from the center of the lens.
(d) Calculate the ratio of the image size to the object size.



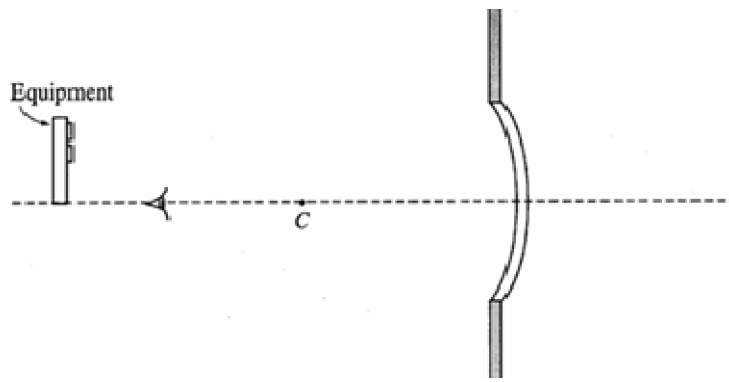
(e) The object *A* is now moved to the right from $x = 6$ cm to a position of $x = 20$ cm, as shown above. Describe the image position, size, and orientation when the object is at $x = 20$ cm.

2002B4B. A marine archaeologist looks out the port of a research submarine, as shown. The port is spherically shaped with center of curvature at point C and radius of curvature r. It is made of a material that has an index of refraction of n_w, the same as the index of refraction of seawater, which is greater than n_a, the index of refraction of air. The archaeologist is located to the left of point C and some equipment in the submarine is located behind the archaeologist. The archaeologist can see through the port, but the port also acts as a mirror so the archaeologist can see the reflection of the equipment.



(a) What is the focal length of the mirror?

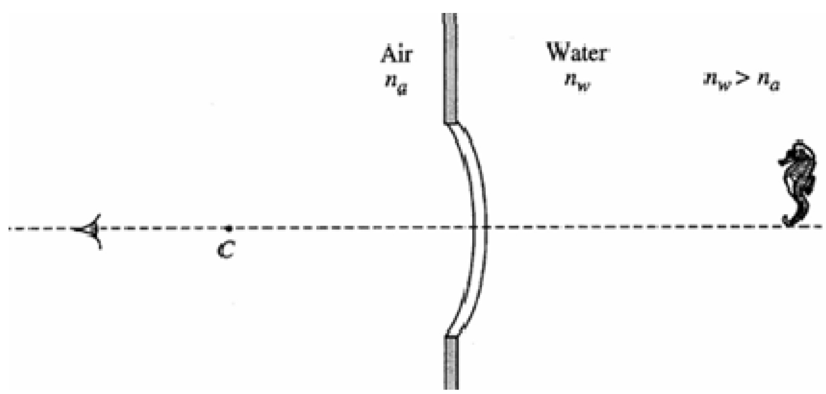
(b) On the following figure, sketch a ray diagram to locate the position of the image of the equipment formed as a result of the mirror effect.



(c) Based on your ray diagram, check the appropriate spaces below to describe the image of the equipment formed as a result of the mirror effect.

i. Image is:____ upright ____ inverted
ii. Image is:____ real ____ virtual
iii. Image is:____ larger than the equipment
____ smaller than the equipment

The archaeologist also observes a seahorse located outside the port directly in front of the archeologist. Due to refraction of light at the inner surface of the port, the seahorse does not appear to the archaeologist to be at its actual location.



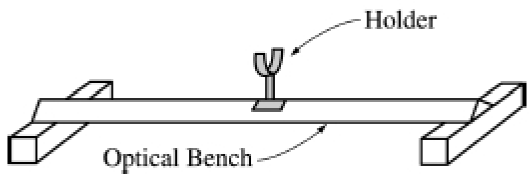
(d) On the figure above, sketch a ray diagram to locate the position of the image of the seahorse formed by the refraction of light at the port.

(e) Based on your ray diagram, check the appropriate spaces below to describe the image of the seahorse, as seen by the archaeologist, formed by the refraction of light at the port.

i. Image is:____upright ____ inverted
ii. Image is:____real ____ virtual
iii. Image is:____ larger than the seahorse ____ smaller than the seahorse

2003B4.

In your physics lab, you have a concave mirror with radius of curvature r = 60 cm. You are assigned the task of finding experimentally the location of a lit candle such that the mirror will produce an image that is 4 times the height of the lit candle.



You have an optical bench, which is a long straight track as shown above. Objects in holders can be attached at any location along the bench. In addition to the concave mirror and the lit candle in holders, you also have the following equipment.

____ convex mirror in holder ____ concave lens in holder ____ convex lens in holder
____ meter stick ____ ruler ____ screen in holder

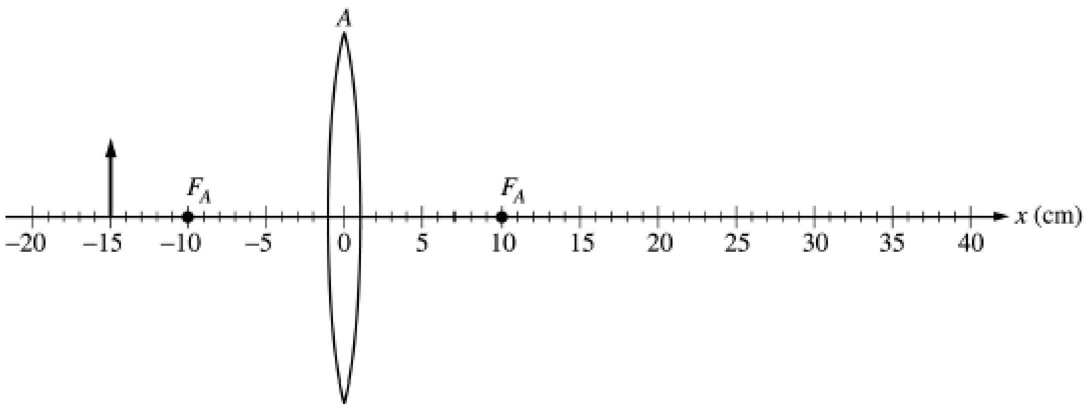
(a) Briefly list the steps in your procedure that will lead you to the location of the lit candle that produces the desired image. Include definitions of any parameters that you will measure.

(b) On the list of equipment before part (a) place check marks beside each additional piece of equipment you will need to do this experiment.

(c) On the scale below, draw a ray diagram of your lab setup in part (a) to show the locations of the candle, the mirror, and the image.

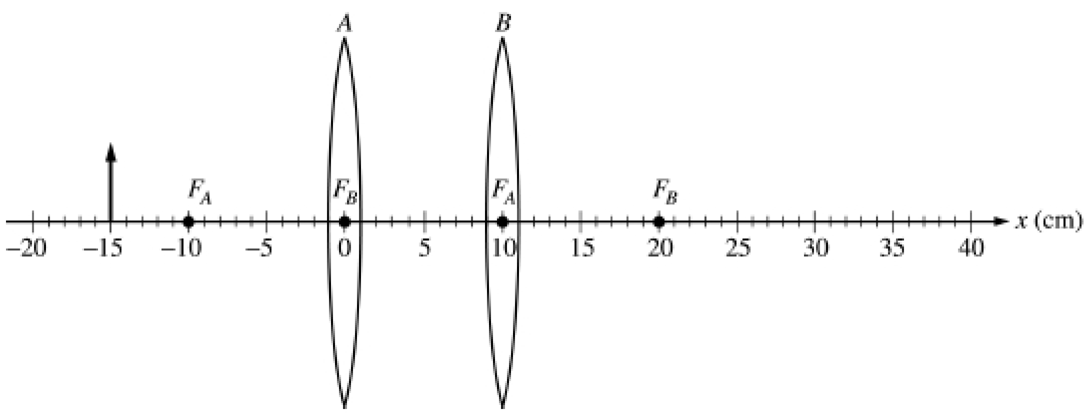
(d) Check the appropriate spaces below to indicate the characteristics of your image.
____ real ____ upright ____ larger than object
____ virtual ____ inverted ____ smaller than object

(e) You complete your assignment and turn in your results to your teacher. She tells you that another student, using equipment from the same list, has found a different location for the lit candle. However, she tells both of you that the labs were done correctly and that neither experiment need be repeated. Explain why both experiments can be correct.



B2003B3.
A thin convex lens A of focal length f_A = 10 cm is positioned on an x-axis as shown above. An object of height 5 cm, represented by the arrow, is positioned 15 cm to the left of lens A.

(a) On the figure above, draw necessary rays and sketch the image produced by lens A.
(b) Calculate the location of the image produced by lens A.
(c) Calculate the height of the image produced by lens A.



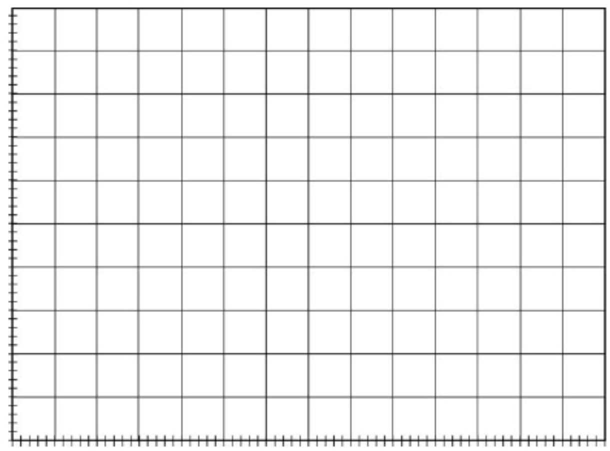
A second thin convex lens B of focal length f_B = 10 cm is now positioned 10 cm to the right of lens A, as shown above.

(d) Determine the location on the x-axis given above of the final image produced by the combination of lenses.
(e) Check the appropriate spaces below to indicate the characteristics of the final image produced by the combination of lenses.
____ inverted ____ larger than the original object
____ upright ____ smaller than the original object
Explain your answers.

2006B4.

A student performs an experiment to determine the index of refraction n of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence θ_i in air and corresponding angles of refraction θ_r in glass. The measurements of the angles for five trials are given in the table below.

Trial	θ_i	θ_r		
1	30°	20°		
2	40°	27°		
3	50°	32°		
4	60°	37°		
5	70°	40°		

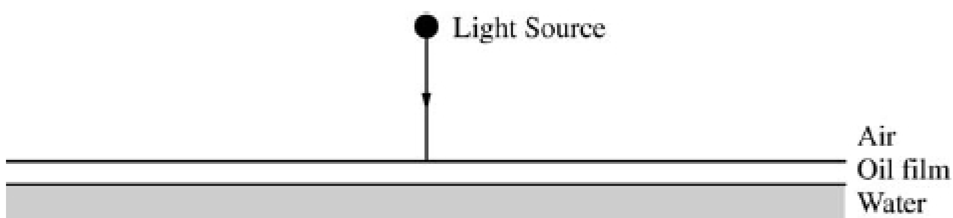


(a) Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

(b) On the grid, plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.

(c) Using the graph, calculate the index of refraction of the glass slab.

The student is also asked to determine the thickness of a film of oil (n = 1.43) on the surface of water (n = 1.33).



Light from a variable wavelength source is incident vertically onto the oil film as shown above. The student measures a maximum in the intensity of the reflected light when the incident light has a wavelength of 600 nm.

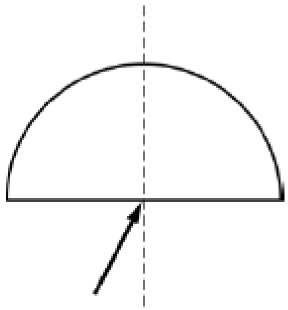
(d) At which of the two interfaces does the light undergo a 180º phase change on reflection?

___The air-oil interface only ___The oil-water interface only

___Both interfaces ___Neither interface

(e) Calculate the minimum possible thickness of the oil film.

B2006B4.



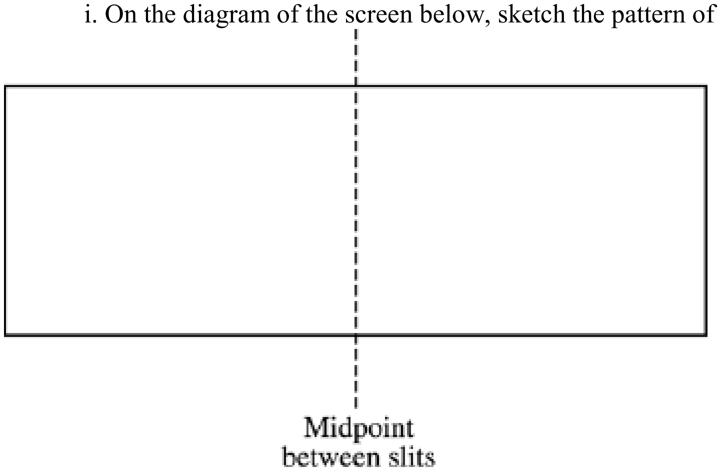
A ray of red light in air (λ = 650 nm) is incident on a semicircular block of clear plastic (n = 1.51 for this light), as shown above. The ray strikes the block at its center of curvature at an angle of incidence of 27°.

(a) Part of the incident ray is reflected and part is refracted at the first interface.
  i. Determine the angle of reflection at the first interface. Draw and label the reflected ray on the diagram above.
  ii. Determine the angle of refraction at the first interface. Draw and label the refracted ray on the diagram above.
  iii. Determine the speed of the light in the plastic block.
  iv. Determine the wavelength of the light in the plastic block.

(b) The source of red light is replaced with one that produces blue light (λ = 450 nm), for which the plastic has a greater index of refraction than for the red light. Qualitatively describe what happens to the reflected and refracted rays.

(c) The semicircular block is removed and the blue light is directed perpendicularly through a double slit and onto a screen. The distance between the slits is 0.15 mm. The slits are 1.4 m from the screen.

  i. On the diagram of the screen below, sketch the pattern of light that you should expect to see.



  ii. Calculate the distance between two adjacent bright fringes

2007B6. You are asked to experimentally determine the focal length of a converging lens.

(a) Your teacher first asks you to estimate the focal length by using a distant tree visible through the laboratory window. Explain how you will estimate the focal length.

To verify the value of the focal length, you are to measure several object distances s_o and image distances s_i using equipment that can be set up on a tabletop in the laboratory.

(b) In addition to the lens, which of the following equipment would you use to obtain the data?

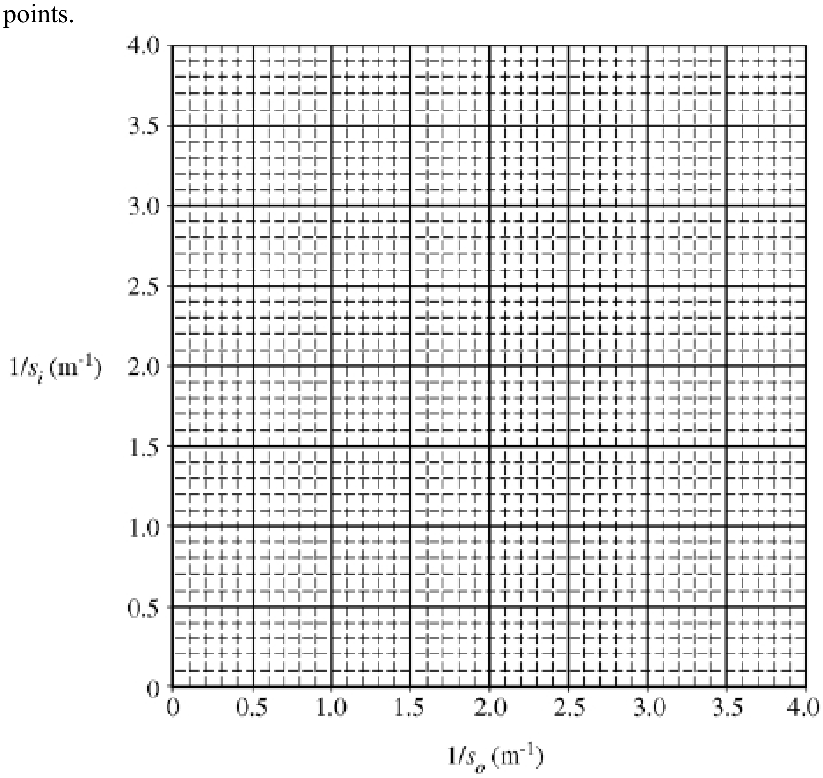
____Lighted candle ____ Candleholder ____ Desk lamp ____ Plane mirror
____ Vernier caliper ____ Meterstick ____ Ruler ____ Lens holder
____ Stopwatch ____ Screen ____ Diffraction grating

(c) On the tabletop below, sketch the setup used to obtain the data, labeling the lens, the distances s_o and s_i , and the equipment checked in part (b).

You are to determine the focal length using a linear graph of $1/s_i$ versus $1/s_o$. Assume that you obtain the following data for object distance s_o and image distance s_i .

Trial #	s_o (m)	s_i (m)	$1/s_o$ (m^{-1})	$1/s_i$ (m^{-1})
1	0.40	1.10	2.5	0.91
2	0.50	0.75	2.0	1.3
3	0.60	0.60	1.7	1.7
4	0.80	0.50	1.2	2.0
5	1.20	0.38	0.83	2.6

(d) On the grid below, plot the points in the last two columns of the table above and draw a best-fit line through the points.



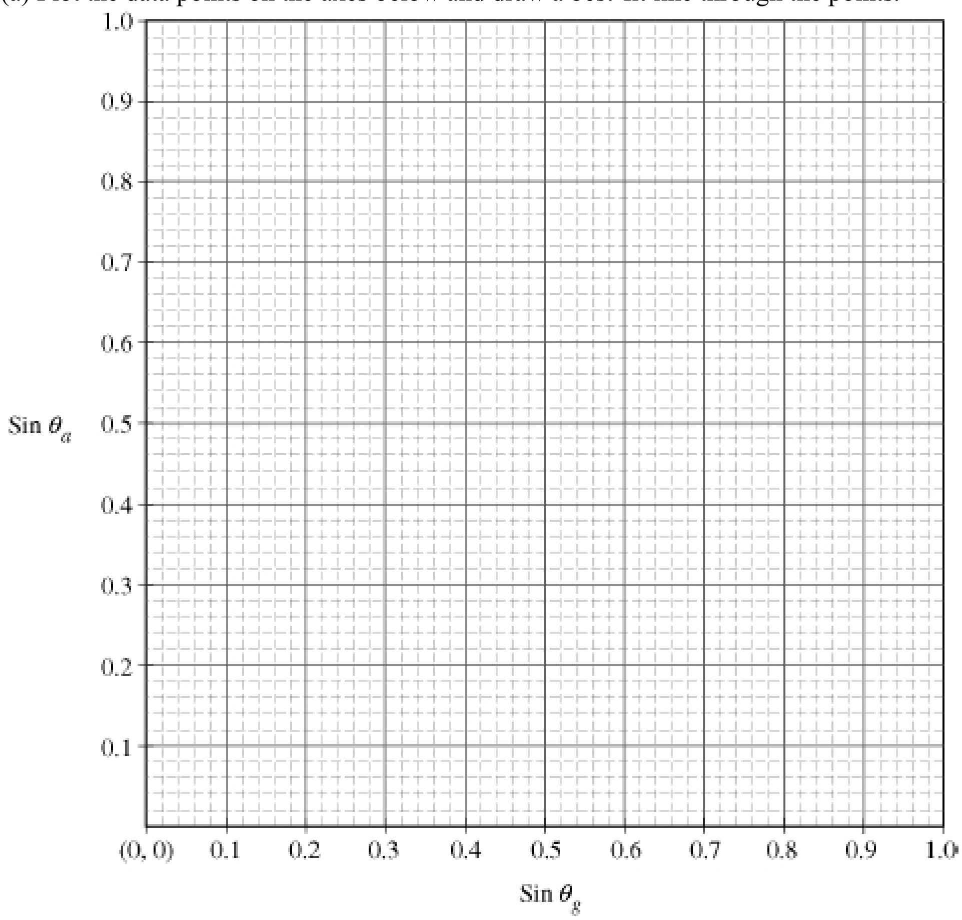
(e) Calculate the focal length from the best-fit line.

B2007B6

A student is asked to determine the index of refraction of a glass slab. She conducts several trials for measurement of angle of incidence θ_a in the air versus angle of refraction θ_g in the glass at the surface of the slab. She records her data in the following table. The index of refraction in air is 1.0.

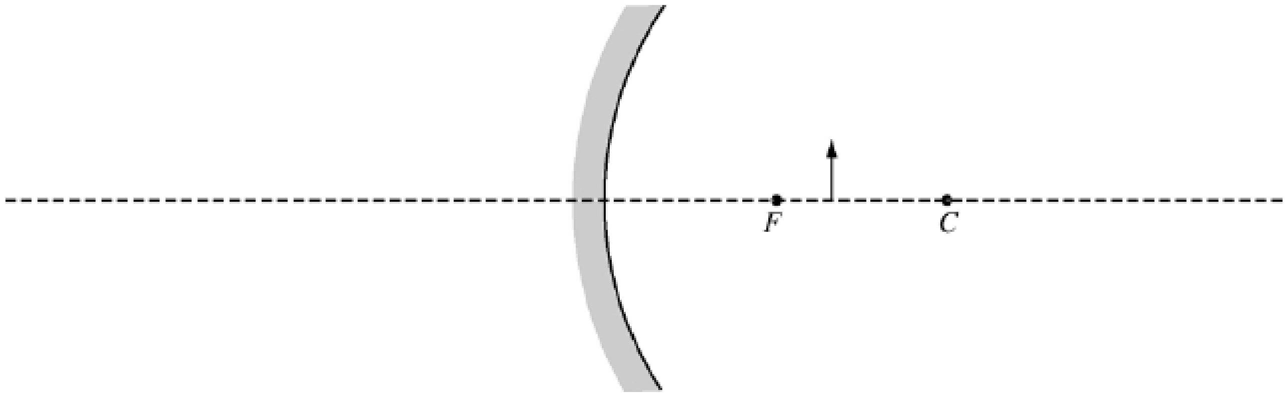
Trial #	θ_g (degrees)	θ_a (degrees)	Sin θ_g	Sin θ_a
1	5.0	8.0	0.09	0.14
2	15	21	0.26	0.36
3	25	39	0.42	0.63
4	35	56	0.57	0.83

(a) Plot the data points on the axes below and draw a best-fit line through the points.

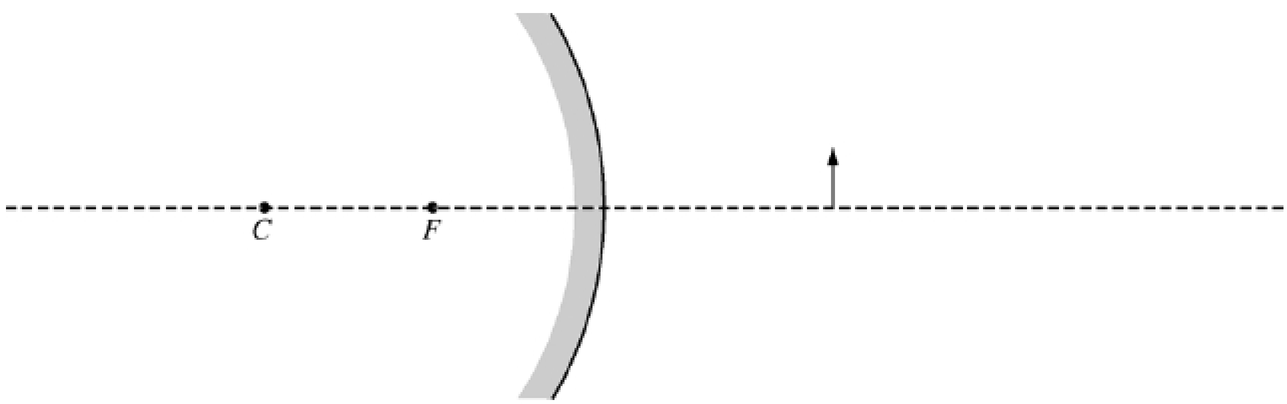


(b) Calculate the index of refraction of the glass slab from your best-fit line.
(c) Describe how you could use the graph to determine the critical angle for the glass-air interface. Do not use the answer to the part (b) for this purpose.
(d) On the graph in (a), sketch and label a line for a material of higher index of refraction.

2008B6.



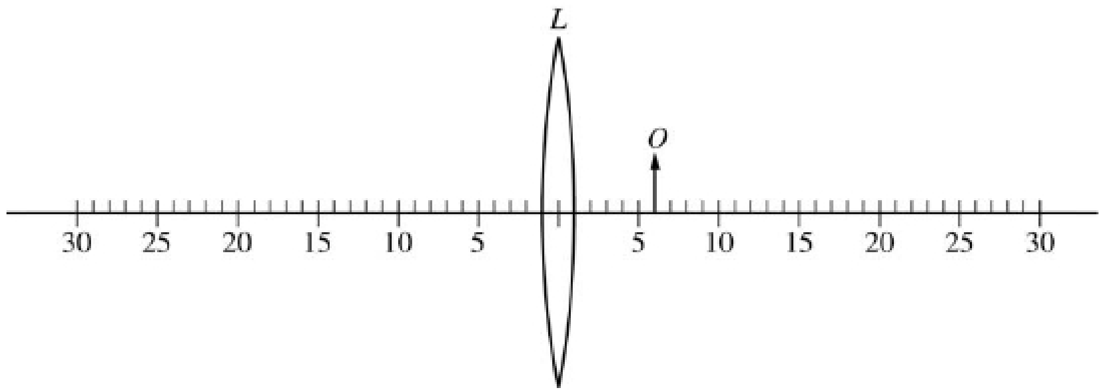
The figure above shows a converging mirror, its focal point F, its center of curvature C, and an object represented by the solid arrow.
(a) On the figure above, draw a ray diagram showing at least two incident rays and the image formed by them.
(b) Is the image real or virtual?
____ Real ____ Virtual
Justify your answer.
(c) The focal length of this mirror is 6.0 cm, and the object is located 8.0 cm away from the mirror. Calculate the position of the image formed by the mirror. (Do NOT simply measure your ray diagram.)
(d) Suppose that the converging mirror is replaced by a diverging mirror with the same radius of curvature that is the same distance from the object, as shown below.



For this mirror, how does the size of the image compare with that of the object?
____ Larger than the object ____ Smaller than the object ____ The same size as the object
Justify your answer.

B2008B6.

A thin converging lens *L* of focal length 10.0 cm is used as a simple magnifier to examine an object *O* that is placed 6.0 cm from the lens.



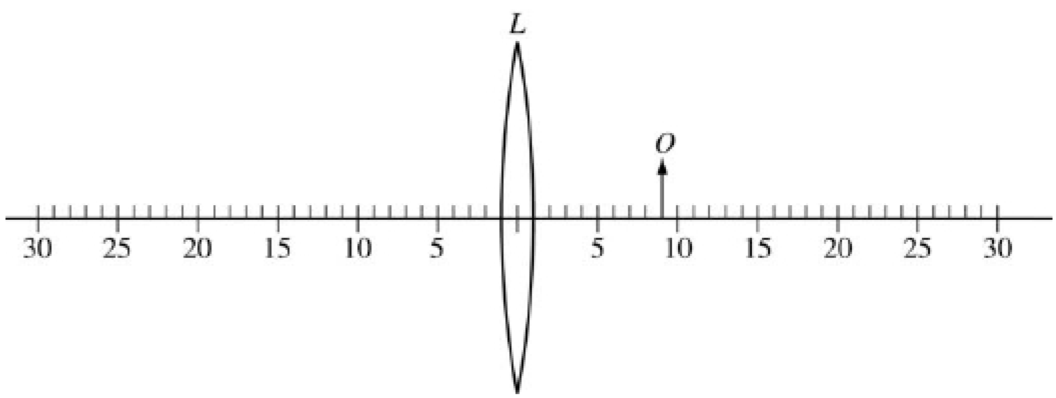
(a) On the figure above, draw a ray diagram showing at least two incident rays and the position and size of the image formed.

(b) i. Indicate whether the image is real or virtual.

____ Real ____ Virtual

ii. Justify your answer.

(c) Calculate the distance of the image from the center of the lens. (Do NOT simply measure your ray diagram.)

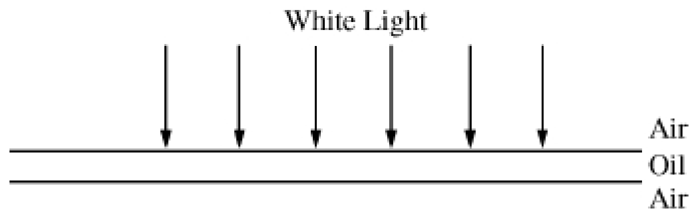


(d) The object is now moved 3.0 cm to the right, as shown above. How does the height of the new image compare with that of the previous image?

____ It is larger. ____ It is smaller. ____ It is the same size.

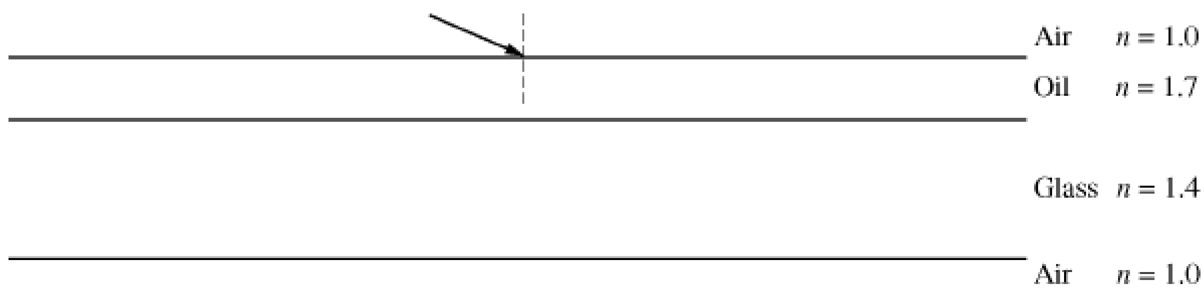
Justify your answer.

B2009B5



A wide beam of white light is incident normal to the surface of a uniform oil film. An observer looking down at the film sees green light that has maximum intensity at a wavelength of 5.2×10^{-7} m. The index of refraction of the oil is 1.7.

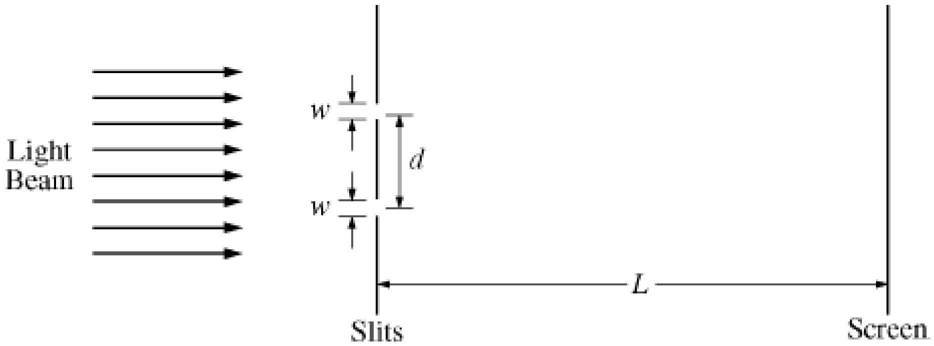
(a) Calculate the speed at which the light travels within the film.
(b) Calculate the wavelength of the green light within the film.
(c) Calculate the minimum possible thickness of the film.
(d) The oil film now rests on a thick slab of glass with index of refraction 1.4, as shown in the figure below. A light ray is incident on the film at the angle shown. On the figure, sketch the path of the refracted light ray that passes through the film and the glass slab and exits into the air. Clearly show any bending of the ray at each interface. You are NOT expected to calculate the sizes of any angles.



NOTE: This is a repeat from the physical optics section but has an important new part in it in bold.

2009B6

In a classroom demonstration, a beam of coherent light of wavelength 550 nm is incident perpendicularly onto a pair of slits. Each slit has a width w of 1.2×10^{-6} m, and the distance d between the centers of the slits is 1.8×10^{-5} m. The class observes light and dark fringes on a screen that is a distance L of 2.2 m from the slits. Your notebook shows the following setup for the demonstration.

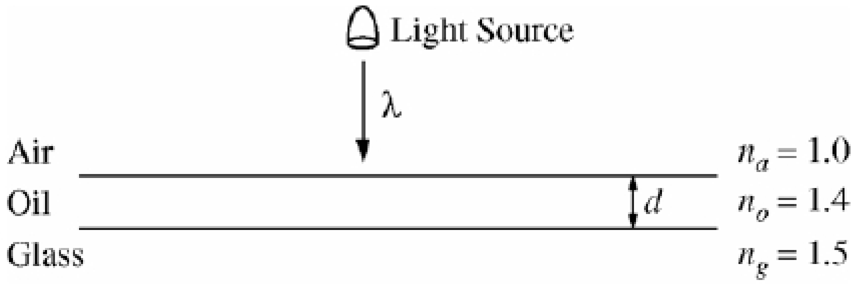


Note: Figure not drawn to scale.

(a) Calculate the frequency of the light.
(b) Calculate the distance between two adjacent dark fringes on the screen.

The entire apparatus is now immersed in a transparent fluid having index of refraction 1.4.
(c) What is the frequency of the light in the transparent fluid?
(d) Does the distance between the dark fringes increase, decrease, or remain the same?
_____ Increase _____ Decrease _____ Remain the same
Explain your reasoning.

Supplemental Problem.



In a classroom demonstration of thin films, your physics teacher takes a glass plate and places a thin layer of transparent oil on top of it. The oil film is then illuminated by shining a narrow beam of white light perpendicularly onto the oil's surface, as shown above. The indices of refraction of air, the oil, and the glass plate are given in the diagram. Standing near the light source, you observe that the film appears green. This corresponds to a wavelength of 520 nm.

(a) Determine each of the following for the green light.

i. The frequency of the light in air

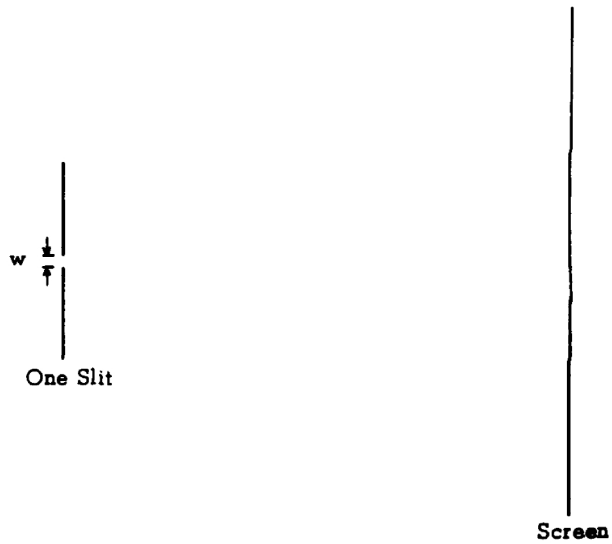
ii. The frequency of the light in the oil film

iii. The wavelength of the light in the oil film

(b) Calculate the minimum thickness of the oil film (other than zero) such that the observed green light is the most intense.

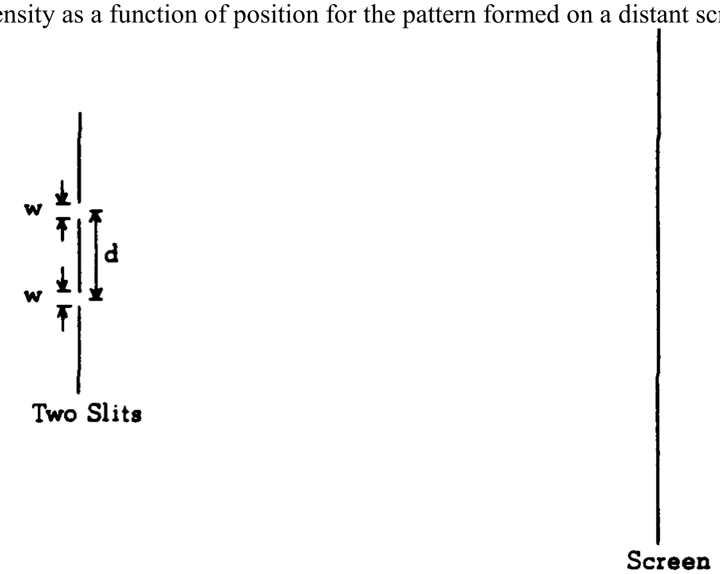
(c) As your teacher changes the angle of the light source, the light you observe from the film changes color. Give an explanation for this phenomenon.

SECTION B – Physical Optics



1975B4.

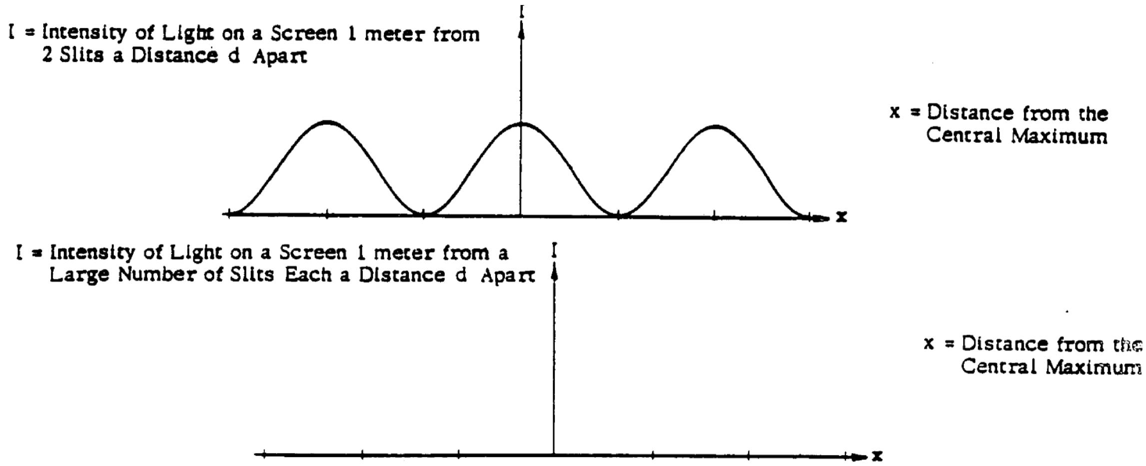
a. Light of a single wavelength is incident on a single slit of width w (w is a few wavelengths.) Sketch a graph of the intensity as a function of position for the pattern formed on a distant screen.



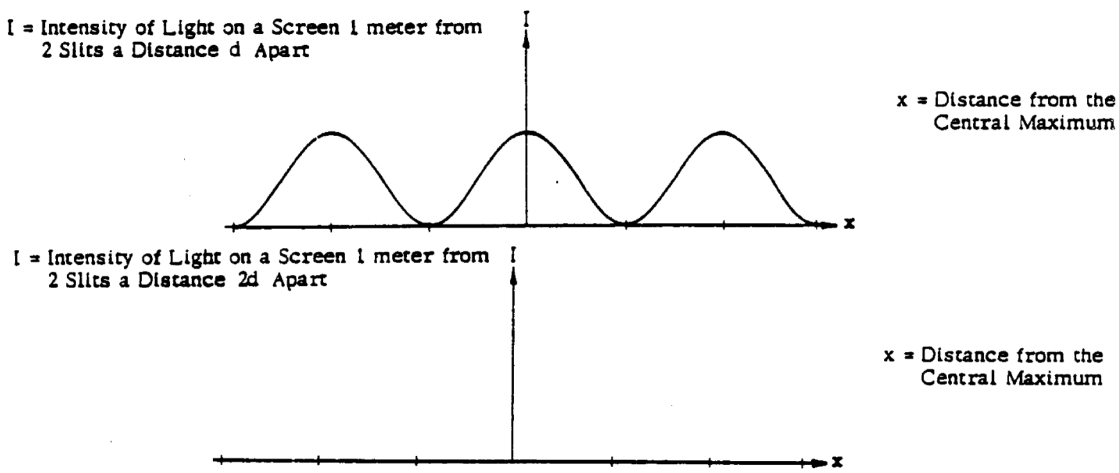
b. Repeat for the case in which there are two slits. The slits are of width w and are separated by a distance d (d >> w). Sketch a graph of the intensity as a function of position for the pattern formed on a distant screen.

1980B4. In the graphs that follow, a curve is drawn in the first graph of each pair. For the other graph in each pair, sketch the curve showing the relationship between the quantities labeled on the axes. Your graph should be consistent with the first graph in the pair.

(a)

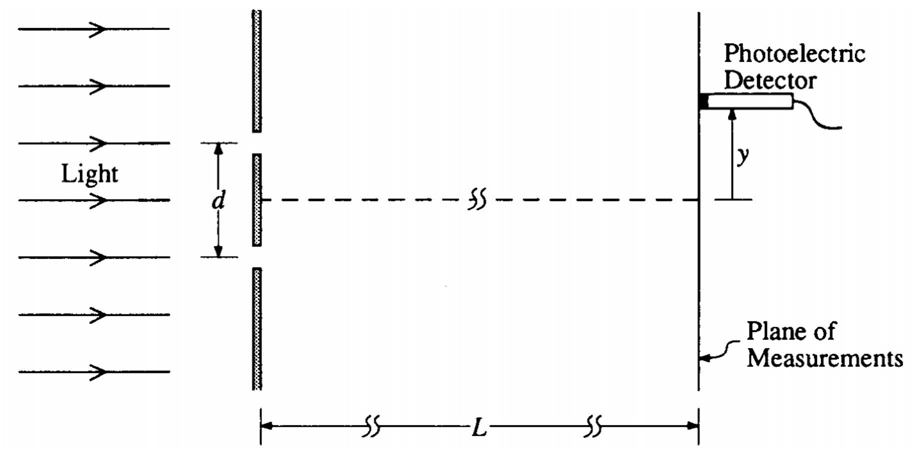


(b)



1985B5. Light of wavelength 5.0×10^{-7} meter in air is incident normally (perpendicularly) on a double slit. The distance between the slits is 4.0×10^{-4} meter, and the width of each slit is negligible. Bright and dark fringes are observed on a screen 2.0 meters away from the slits.

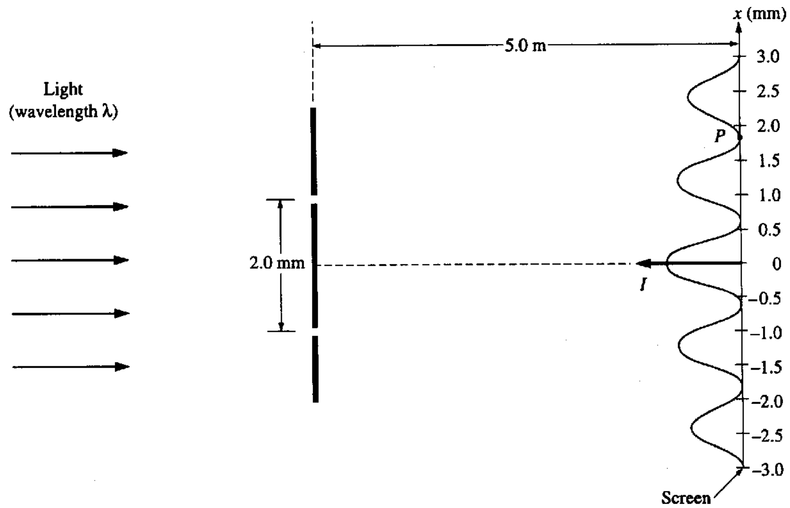
a. Calculate the distance between two adjacent bright fringes on the screen.



1991B6. Light consisting of two wavelengths, $\lambda_a = 4.4 \times 10^{-7}$ meter and $\lambda_b = 5.5 \times 10^{-7}$ meter, is incident normally on a barrier with two slits separated by a distance d. The intensity distribution is measured along a plane that is a distance L = 0.85 meter from the slits as shown above. The movable detector contains a photoelectric cell whose position y is measured from the central maximum. The first-order maximum for the longer wavelength λ_b occurs at $y = 1.2 \times 10^{-2}$ meter.

a. Determine the slit separation d.

b. At what position, Y_a, does the first-order maximum occur for the shorter wavelength λ_a?



1996B3. Coherent monochromatic light of wavelength λ in air is incident on two narrow slits, the centers of which are 2.0 mm apart, as shown above. The interference pattern observed on a screen 5.0 m away is represented in the figure by the graph of light intensity I as a function of position x on the screen.

a. What property of light does this interference experiment demonstrate?

b. At point P in the diagram, there is a minimum in the interference pattern. Determine the path difference between the light arriving at this point from the two slits.

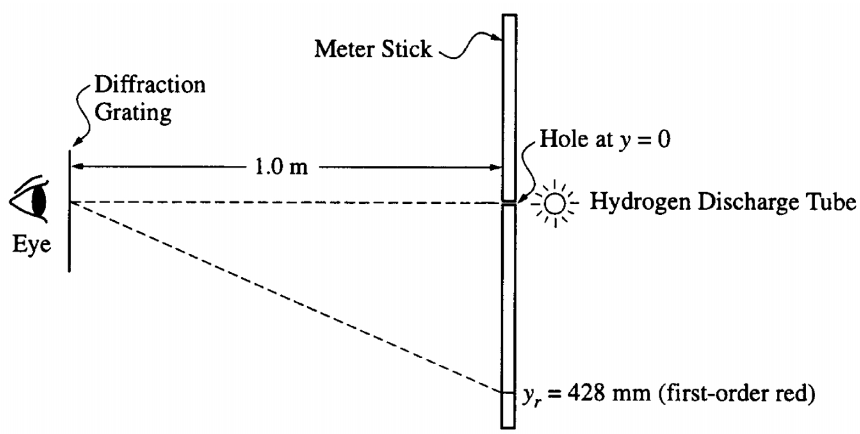
c. Determine the wavelength, λ, of the light.

d. Briefly and qualitatively describe how the interference pattern would change under each of the following separate modifications and explain your reasoning.

   i. – omitted –

   ii. One of the slits is covered.

   iii. The slits are moved farther apart.

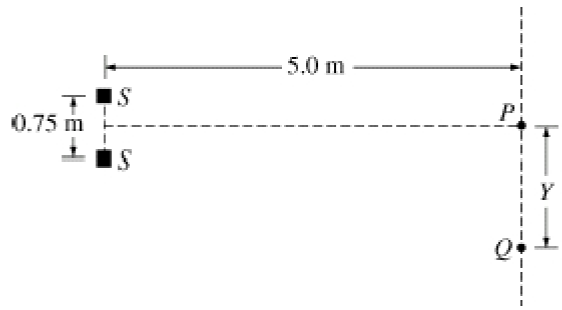


1998B7. A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance y_r = 428 mm from the hole.

a. Calculate the wavelength of the red line in the hydrogen spectrum.

c. Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of the one with 600 lines/mm.

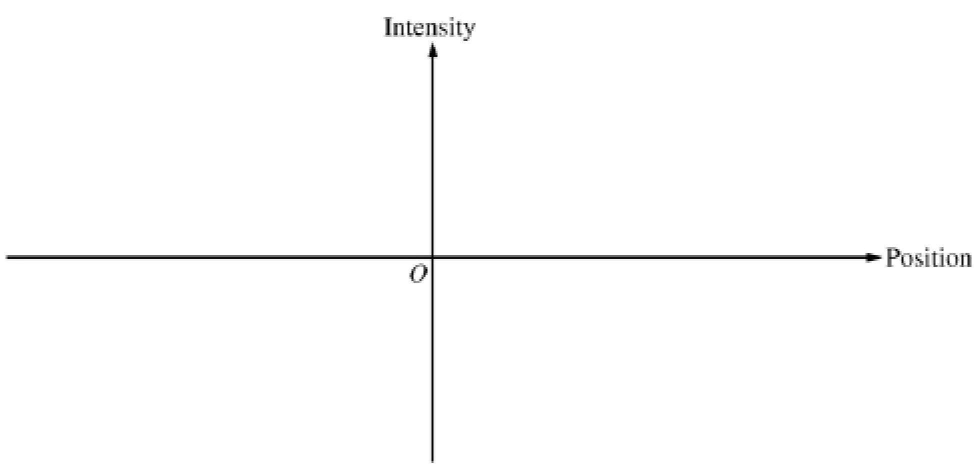
2004B4. Two small speakers S are positioned a distance of 0.75 m from each other, as shown in the diagram. The two speakers are each emitting a constant 2500 Hz tone, and the sound waves from the speakers are in phase with each other. A student is standing at point P, which is a distance of 5.0 m from the midpoint between the speakers, and hears a maximum as expected. Assume that reflections from nearby objects are negligible. Use 343 m/s for the speed of sound.



(a) Calculate the wavelength of these sound waves.
(b) The student moves a distance Y to point Q and notices that the sound intensity has decreased to a minimum.

Calculate the shortest distance the student could have moved to hear this minimum.
(c) Identify another location on the line that passes through P and Q where the student could stand in order to observe a minimum. Justify your answer.
(d) i. How would your answer to (b) change if the two speakers were moved closer together? Justify your answer.
ii. How would your answer to (b) change if the frequency emitted by the two speakers was increased? Justify your answer.

2005B4. Your teacher gives you a slide with two closely spaced slits on it. She also gives you a laser with a wavelength $\lambda = 632$ nm. The laboratory task that you are assigned asks you to determine the spacing between the slits. These slits are so close together that you cannot measure their spacing with a typical measuring device.
(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.
___ Meterstick ___ Ruler ___ Tape measure ___ Light-intensity meter
___ Large screen ___ Paper ___ Slide holder ___ Stopwatch
(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify carefully what measurements you will need to make.
(c) On the axes below, sketch a graph of intensity versus position that would be produced by your setup, assuming that the slits are very narrow compared to their separation.



(d) Outline the procedure that you would use to make the needed measurements, including how you would use each piece of the additional equipment you checked in (a).
(e) Using equations, show explicitly how you would use your measurements to calculate the slit spacing.

B2005B4. Your teacher gives you two speakers that are in phase and are emitting the same frequency of sound, which is between 5000 and 10,000 Hz. She asks you to determine this frequency more precisely. She does not have a frequency or wavelength meter in the lab, so she asks you to design an interference experiment to determine the frequency. The speed of sound is 340 m/s at the temperature of the lab room.

(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.
___ Speaker stand ___ Meterstick ___ Ruler ___Tape measure
___ Stopwatch ___ Sound-level meter

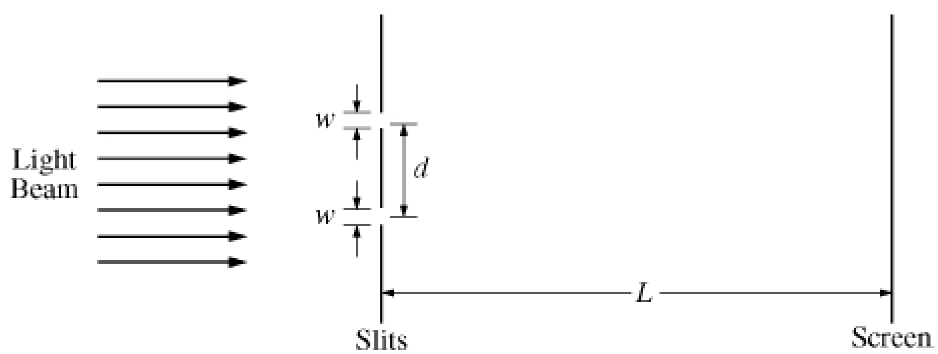
(b) Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify what measurements you will need to make.

(c) Briefly outline the procedure that you would use to make the needed measurements, including how you would use each piece of equipment you checked in (a).

(d) Using equations, show explicitly how you would use your measurements to calculate the frequency of the sound produced by the speakers.

(e) If the frequency is decreased, describe how this would affect your measurements.

2009B6. In a classroom demonstration, a beam of coherent light of wavelength 550 nm is incident perpendicularly onto a pair of slits. Each slit has a width w of 1.2×10^{-6} m, and the distance d between the centers of the slits is 1.8×10^{-5} m. The class observes light and dark fringes on a screen that is a distance L of 2.2 m from the slits. Your notebook shows the following setup for the demonstration.



Note: Figure not drawn to scale.

(a) Calculate the frequency of the light.

(b) Calculate the distance between two adjacent dark fringes on the screen.

AP Physics Multiple Choice Practice – Optics – ANSWERS

SECTION A – Geometric Optics

	Solution	Answer
1.	Using the math, $1/f = 1/d_o + 1/d_i$, and $M = -d_i / d_o$ … d_i +0.6 $M = -3$ …	C
2.	Use $n_1 \lambda_1 = n_2 \lambda_2$	D
3.	More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's.	D
4.	If you look carefully you can see these are both 3–4–5 triangles and are also the same triangle flipped. The hypotenuse of each is 1.5 m. Using the sides of the triangles, we have $\sin\theta_1 = o/h = 0.8/1.5$ for the bottom triangle, and $\sin\theta_2 = o/h = 1.2/1.5$ for the top triangle. Now use $n_1 \sin\theta_1 = n_2 \sin\theta_2$ … $n_1 (0.8/1.5) = (1)(1.2/1.5)$ … $n_1 = 1.2/0.8 = 3/2 = 1.5$	B
5.	Less–More bend towards. But it can't be E because that would only happen if the incoming angle was also 0.	D
6.	The lens shown has thick in the center and thin on the outside which makes a converging lens. In converging lenses, all of the real images are inverted and can be any size, but the virtual images are formed in a magnifying lens scenario and are always larger and upright.	A, B
7.	A horizontal beam approaching a converging lens bends and converges through the focal point.	D
8.	More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's.	D
9.	Assuming total internal reflection didn't happen, More–Less dense bend away.	C
10.	Need a magnifying glass which is choice B.	B
11.	Generally when we go from more–less we should always check the critical angle first rather than assuming the ray will refract and bend away. Choice D might be correct, but not until we first check the critical angle for total internal reflection. Use $n_i \sin\theta_c = n_r \sin(90)$, n_i=1.5, n_r=1 $\theta_c = 41.8°$. Since our incoming angle (60) is larger than the critical angle, total internal reflection will occur and you will get choice E.	D
12.	Using the math, $1/f = 1/d_o + 1/d_i$, and $M = -d_i / d_o$ … d_i +20 $M = -1$ …	B, D
13.	When light from multiple locations pass through a given part of a lens to form an image, only a small portion of a lens is needed to form the image. The more of a lens, the more light rays that can be bent by it to each image location. This simply makes the image brighter. By covering half the lens, all of the incoming rays still bend all the same ways but there are less total rays being bent to given locations on the image so it is dimmer. This can easily be seen by looking at a lens that has only horizontal rays approaching it. All of these rays converge to the focal point; covering a portion of the lens still focuses the rays on the focal point, just less of them.	A
14.	More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's … this shows that $n_2 > n_1 > n_3$. More n means less speed so $v_3 > v_1 > v_2$	A
15.	It's a diverging lens so light bends away from what the horizontal path would be without the lens.	B
16.	The focal point is = R/2. Then use the math $1/f = 1/d_o + 1/d_i$ … and $d_i = 10$	C

17. From n=c/v. $n_1 = c/v_1$ … $1.5 = c / v_X$ … $v_X = c / 1.5$ C
$n_2 = c/v_2$ … $2.0 = c / v_Y$ … $v_Y = c / 2$

The problem defines $v_Y = v$
So $v = c/2$, $c = 2v$ … then subbing that into the v_x equation we have $v_X = (2v) / 1.5 = 1.33$ v

18. First find the λ in the film. $n_{air} \lambda_{air} = n_{film} \lambda_{film}$ … $(1)(600) = (1.5) \lambda_{glass}$ … $\lambda_{glass} = 400$ nm B
As the light travels through the two boundaries, you get a ½ λ phase shift (flip) at the first boundary but no shift at the second boundary. Therefore, you need to make another ½ λ of phase difference total by traveling in the film thickness to produce constructive interference to reinforce the orange wavelength. When the glass thickness is ¼ of the λ in the glass, the light will travel up and down to make the extra ½ λ needed. So ¼ of the λ in the glass gives you 100 nm thickness needed.

19. Do the math twice. For the first lens. $1/f = 1/d_o + 1/d_i$ … $d_i = + 14$ cm (real). So this first 'pre–image' is formed 14 cm to the right of the first lens, which means it is 16 cm from the second lens. Now redo the math using this 'pre–image' as the object located 16 cm away from the second lens. $1/f = 1/d_o + 1/d_i$ … $d_i = + 26.67$ cm. C

20. The magnification is M=2. Using $M = -d_i / d_o$ … $d_i = -2d_o$ Lets assume a value of $d_o = 10$, then $d_i = -20$, and from $1/f = 1/d_o + 1/d_i$, the focal point is 20. Now redo the math with the focal point for the diverging lens being negative and the new $d_i = -6.67$, giving a new M=0.67 C

21. A convex lens is a converging lens. When the object is in front of the focal point, it acts as a magnifying glass. A

22. Similar to question 18, except both boundaries undergo phase shifts, so 1 full extra wavelength is needed using the soap thickness. This requires the thickness to be ½ λ_{soap} giving the answer. B

23. Draw ray diagrams for each, or make up numbers and do the math for each to see which works. D

24. When traveling between mediums, sound behaves opposite from light. As given in the problem the sound travels faster in the denser rock. When the sound speeds up, the wavelength increases and the frequency stays the same. D

25. Diverging lens always produces the same object type no matter what. B

26. The transmitted wave never has a phase change, but hitting the more dense block causes the reflection to flip 180 degrees. D

27. More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's … this shows $n_2 > n_1 > n_3$. More n means less speed, so $v_3 > v_1 > v_2$. Frequency does not change as the light passes from one medium to another. A,B

28. Based on various ray diagrams drawn with the object behind the focal point, the image is always real but its size depends on where it is in location to the focal point. B

29. First determine the λ_{film}. $n_1 \lambda_1 = n_{film} \lambda_{film}$ … $(1)(640) = (1.33) \lambda_{film}$ … $\lambda_{film} = 481$ nm. C

When the wave reaches each boundary is undergoes a ½ λ phase shift at each boundary so this essentially cancels out the phase shift. To not reflect any light, we want to have destructive interference. In order to get destructive interference we need to get a total of ½ λ or 1 ½ λ or 2 ½ λ … phase differences from moving in the film thickness. These phase differences require a thickness equal to ¼λ_{film}, ¾ λ_{film}, 5/4 λ_{film} … 360 nm thickness matches the ¾λ_{film} possibility.

30. For air–film–glass of progressively increasing index, to produce destructive interference we need ¼ of a wavelength in the coating. See question 43 for the reason. A

31. For all three diagrams, there is a ½ λ phase shift when entering the film but no phase shift when exiting. To produce constructive interference, a total extra phase different of ½ λ from moving in the film thickness is needed so odd multiples of ¼ λ will produce constructive interference. A

32. Draw a ray diagram. C

33. A magnifying glass is a lens, and is produced by a converging lens. It is virtual. A

34. Using the math, $1/f = 1/d_o + 1/d_i$, and $M = -d_i / d_o$ … $d_i = -0.10$ m, $M = +0.33$ D

35. Converging lenses make real images but they are always inverted. D

36. When in front of the focal point of a converging lens, it acts as a magnifying glass. The other optical instruments can never make larger images. A

37. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = -60$, since its virtual, the image is on the same side as the object which is why it is in the left. You would look through this lens from the right side. A

38. A fact about refraction problems, the angles going one way would be the same as the angles going to other way assuming total internal reflection does not occur. D

39. Converging lenses have centers that are thick and top and bottom parts that are thinner. B

40. In flat (plane) mirrors, the image is simply flipped to the other side of the mirror. D

41. Choice I. is true because a soap bubble is a thin film. The colors produced are due to the reinforcement of different λ colors due to variations in the thickness of the soap bubble. In order to see these interference results, the thickness of the film must be similar in magnitude to the wavelength of the light. Since the film is so small, this shows that light has a very small wavelength. Choice II. also shows light has a very small wavelength because a diffraction grating has very tiny slits in it and to produce the pattern seen the wavelength of the light has to be on a similar scale as the size of the openings. Choice III. is not true because all waves regardless of their wavelength bend and it does not reflect on their wavelength size. C

42. From practicing ray diagrams, this should be known. Or a sample could be done to determine it. Mathematically this can be shown by using an extreme example. Suppose $d_o = 1000$, and $f = 10$. Using the lens equation, $d_i = 10.1$. Then decrease d_o down to 20 and $d_i = 20$. So for the range of values of d_o larger than 20, the image distance will fall between 10–20 which is between f and 2f. D

43. Light from a distant star is assumed to be all horizontal. Horizontal light hitting a concave mirror will all converge at the focal point to form an image of the star directly on the focal point. With a radius of curvature = 1m, the focal point is 0.5 m. B

44. When light goes in higher indices of refraction, it slows down. Since $v = f\lambda$ and f remains constant, when v decreases λ decrease with it. D

45. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = -18$ … then $M = -d_i / d_o$ … $M = 3$ D

46. Draw the ray diagram, or makeup some numbers and do the math. D

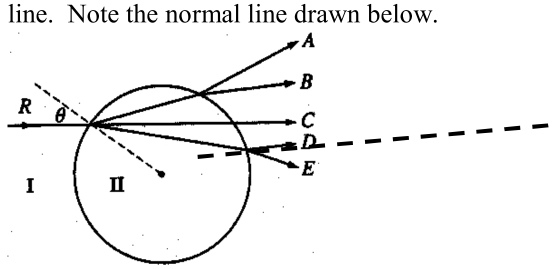
47. If the angle in equals the angle out in a 3 tier medium arrangement, then the substances on the outsides must be the same. A

48. The larger the difference between n's the more the rays bend. When the water is added, the difference between n's is less so the amount of bending is less. D

49. When an object is placed in front of the focal point of a converging lens, the lens acts as a magnifying glass. A

50. The film has a higher n compared to both sides, such as soap surrounded by air. So as the light ray hits the first boundary it makes a ½ λ phase flip, but does not make the flip at the second boundary. To be constructive, we need to cover a total of ½ λ extra phase shift due to traveling in the film thickness. So the thickness should be ¼ λ_{film}. D

51. Medium I (air) is surrounding the sphere on both sides. As it enters the sphere, it goes less–more so bends towards the normal line (leaving D or E as the possibly answers). When the ray reaches the far edge of the sphere, it goes from more–less so should bend away from the normal line. Note the normal line drawn below. D



52. This should be the opposite of the scenario in the last question. A

53. When light from multiple locations pass through a given part of a lens to form an image, only a small portion of a lens is needed to form the image. The more of a lens, the more light rays that can be bent by it to each image location. This simply makes the image brighter. By covering half the lens, all of the incoming rays still bend all the same ways but there are less total rays being bent to given locations on the image so it is dimmer. This can easily be seen by looking at a lens that has only horizontal rays approaching it. All of these rays converge to the focal point; covering a portion of the lens still focuses the rays on the focal point, just less of them. D

54. All waves demonstrate the listed choices. C

55. Bending of a wave (refraction) is due to the speed change at an angle. The more the speed changes, the more the bending. Hence, the violet bends more so must have a larger speed change (more slowing), so the red is faster. *Additionally, we can note that since the violet slows and bends more, the index of refraction in glass for a violet light is higher than the index for a red light.* B,D

56. Based on the law of reflection, the angle of reflection must be the same as the incoming angle. When the light enters the ice it is going more–less so bends away from the normal. This means that θ_r is larger than θ_i. A

57. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = -1.2$. Its virtual so its on the same side as the object, which puts the image on the left side of the lens. A

58. This is a magnifying glass, which can be memorized or the math can be done to prove the answer. D

59. From the diagram, the angle at the bottom of the small top triangle is 30° so when we draw the normal line on that slanted interface, the angle of incidence there is 60°. We are told this is the critical angle which means the angle of refraction of the scenario is 90°. Now we use C

$n_i \sin \theta_c = n_r \sin (90)$ … $n_i \sin(60) = (1)(1)$ … $n_i = 1/ \sin 60$ … $n_i = \dfrac{1}{\left(\dfrac{\sqrt{3}}{2}\right)}$

Rationalizing gives us the answer.

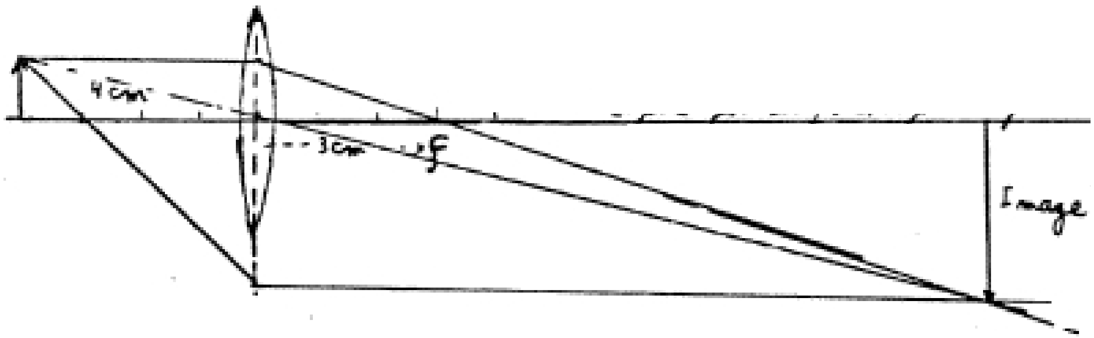
SECTION B – Physical Optics

	Solution	Answer
1.	Using $m\lambda = d \sin \theta$, the value of $\sin \theta$ is the same for both sources since the location of the spot is the same, but the first source is at m=2, and the second source is at m=3. Equating $d \sin \theta$ for each gives $m_1 \lambda_1 = m_2 \lambda_2$ … $(2)(660) = 3 (\lambda_2)$ … $\lambda_2 = 440$ nm.	C
2.	1000 lines/cm gives a line spacing d = 1/1000 cm/line = $1x10^{-5}$ m/line. $\lambda = 7x10^{-7}$ m. With diffraction gratings, we usually assume the small angle approximation does not work, so we find θ then use the geometry with $\tan \theta$ or another trig function to find Y. Do this for each spot. m=1. $m\lambda = d \sin \theta$ $(1)(7x10^{-7}) = (1x10^{-5}) \sin \theta$ $\theta = 4.01°$ … $\tan \theta = o/a$ … $Y_1 = 0.14$ m Repeat for m=3 … $Y_3 = 0.43$ m. Subtract $Y_3 – Y_1$ to find the distance between = 0.29 m *Note: Since the angle θ here actually came out to be small, the x/L small angle approximation could be used and the spacing x between spots could be assumed to be equal as well, so you could simply find x for the first spot and double it to find the spacing 1 to 3.*	B
3.	From $m\lambda = dx / L$, d x2 needs L x2 also.	D
4.	By definition, when the path difference equals ½ λ or any odd multiple of ½ λ's for sources of the same λ, there will be destructive interference.	D
5.	Based on $m\lambda = dx / L$ we want to increase x. d is separation of slits and less d means more x	D
6.	Since the slits are narrow, we can use $m\lambda = d \sin \theta$, but since θ is clearly large we cannot use the x/L small angle approximation. From the given diagram, the geometry shows $\sin \theta = o/h = 3/5$ .. rather than finding θ, we will just use this value for $\sin \theta$ and plug in … $m\lambda = d \sin \theta$ … $(1)(0.12) = d(3/5)$	C
7.	This is still a double slit pattern because there is still light making it through both slits. One of the light sources has reduced its amplitude; which means when it meets the second light source it will cause less interference than it originally did. This means less constructive interference and less destructive interference also. So bright spots become less bright, and dark spots become brighter.	D

SECTION A – Geometric Optics

1974B3.

a)



b) $1/f = 1/d_o + 1/d_i$ … $1/3 = 1/4 + 1/d_i$ … $d_i = 12$ cm

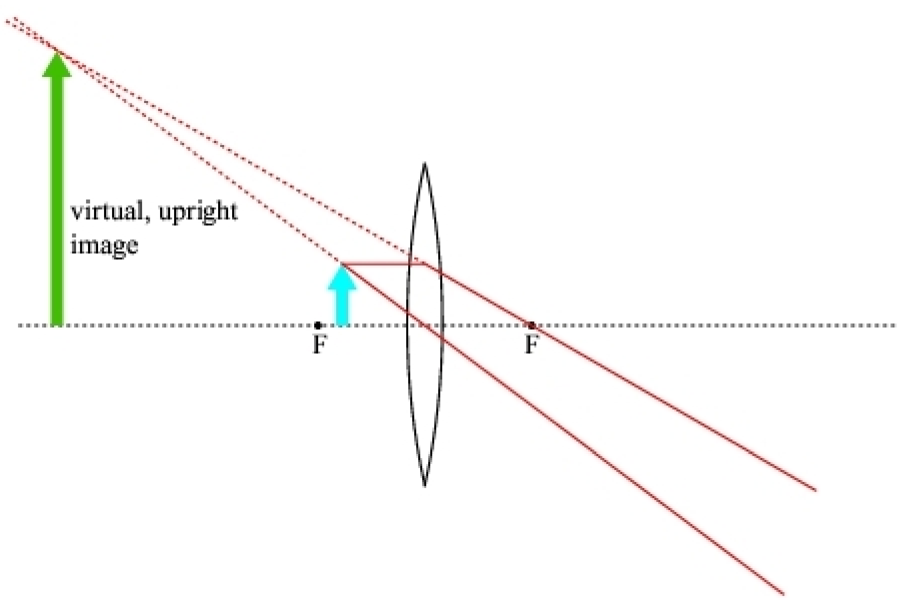
c) $M = -d_i / d_o$ … $M = -12/4 = -3$ … $M = h_i / h_o$ … $-3 = h_i / 1\text{cm}$ … $h_i = -3\text{cm}$

1976B6.

a) $1/f = 1/d_o + 1/d_i$ … $1/8 = 1/6 + 1/d_i$ … $d_i = -24$ cm, left of lens, virtual

b) $M = -d_i / d_o$ … $M = -(-24) / 6 = +4$ … $M = h_i / h_o$ … $4 = h_i / 1$ cm … $h_i = 4$ cm, upright

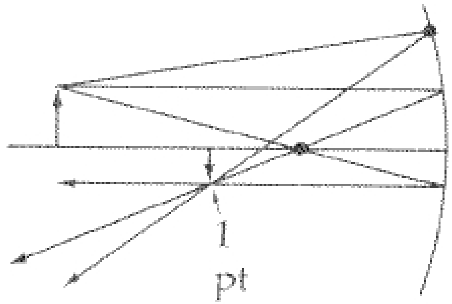
c)



d) Magnifying glass, or telescope / microscope.

1978B5.

a)



b) $1/f = 1/d_o + 1/d_i$ … $1/10 = 1/20 + 1/d_i$ … $d_i = 15$ cm

c) $M = -d_i / d_o$ … $M = -15/30 = -0.5$ … $M = h_i / h_o$ … $-0.5 = h_i / 6\text{cm}$ … $h_i = -3\text{cm}$

d) Reflection Ray PQ is shown in the diagram as the topmost ray. For this ray, the incoming θ = reflection θ.

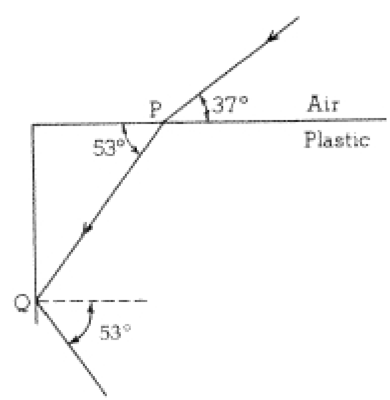
1979B6.

a) Note: The angles given are tricks. They are not measured from the normal, we must use the angle from normal.
Air → Plastic $n_i \sin\theta_i = n_r \sin\theta_r$, (1) sin (53) = n_r sin(37) $n_r = 1.33$

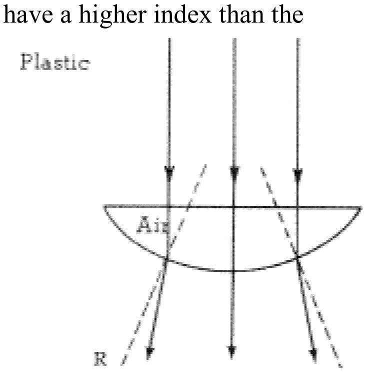
$n = c/v$ $1.33 = 3\times10^8 / v$ $v = 2.26 \times 10^8$ m/s

b) Check the critical angle Plastic → Air. $n_i \sin\theta_c = n_r \sin(90)$ …
(1.33) $\sin\theta_c = (1)$ … $\theta_c = 48.75°$

The incoming angle (53°) is larger than the critical angle, so total internal reflection will occur.

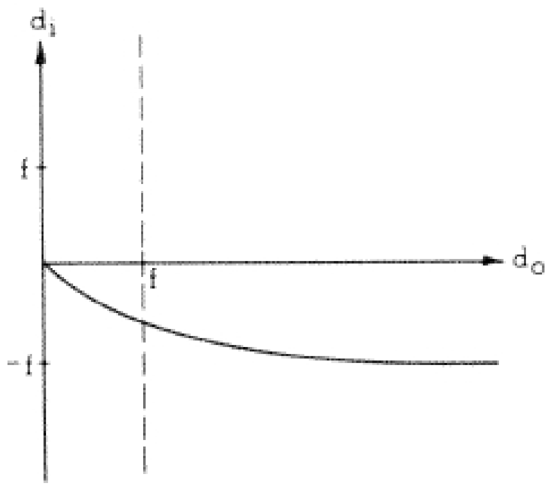


c) This looks like a converging lens, but in lens problems, the lenses always have a higher index than the surrounding material. Since this 'air lens' has a smaller index of refraction it will behave the opposite as a normal lens would. From a simple refraction standpoint, there will be no refraction entering the air since the ray is perpendicular to the surface. Then on exiting, as you move less–more dense the ray bends towards the normal.



1980B4.

e) Based on $1/f = 1/d_o + 1/d_i$

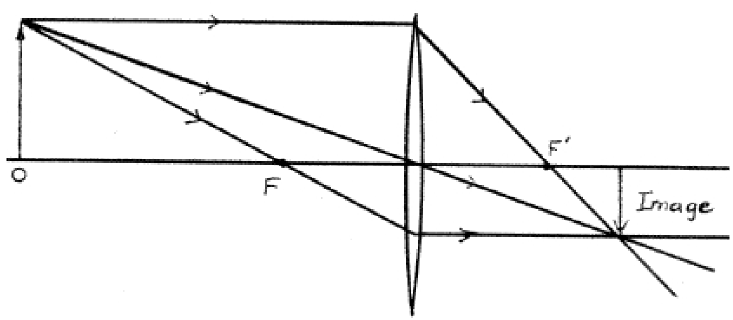


Rearrange for y as function of x (make f – since concave)
$1/d_i = (-1/f) + (-1/d_o)$ ..
the focal point term is negative and constant so …

As d_o increases the $1/d_o$ term decreases adding less and less – values to the right side of the equation. When d_o gets very large the right side becomes constant.

1981B5.

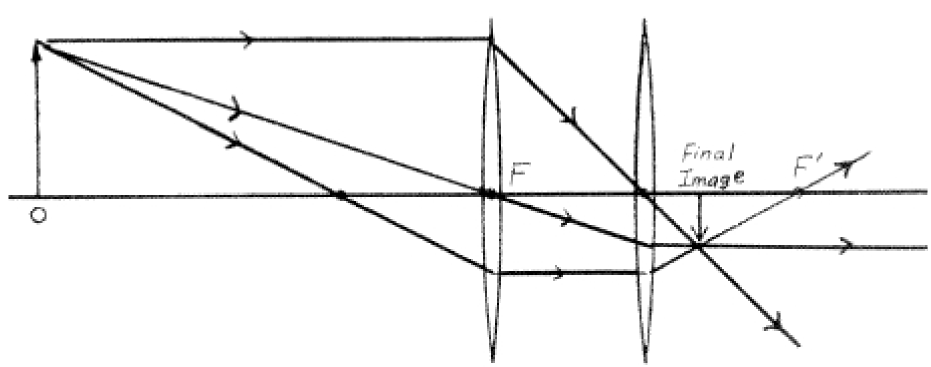
a)



b) This is a real image. The image is on the other side of the lens. It is 'projectable' into real space. The math below also proves that its real

c) $1/f = 1/d_o + 1/d_i$ … $1/6 = 1/18 + 1/d_i$ … $d_i = 9$ cm

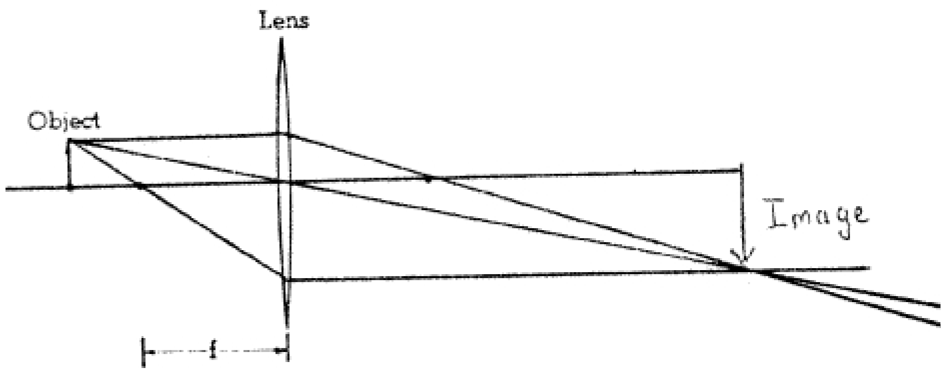
d)



1982B6.

a) $1/f = 1/d_o + 1/d_i$ … $1/f = 1/(3f/2) + 1/d_i$ … $d_i = 3f$

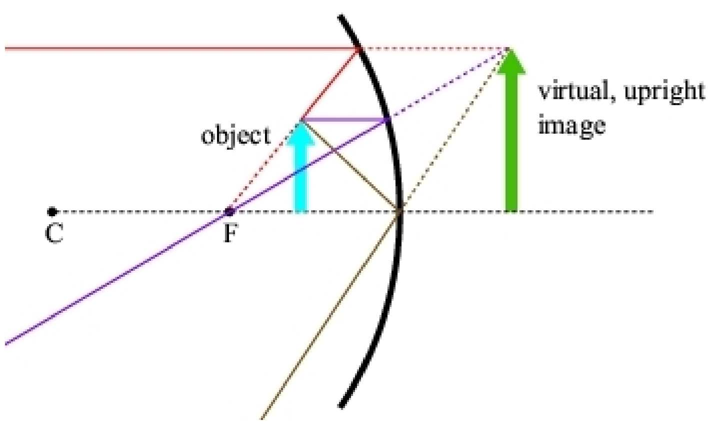
b)



c) The new lens makes a larger magnification. $M = -d_i / d_o$ → with the same d_o, d_i must have increased. Then based on $1/f = 1/d_o + 1/d_i$, to get a larger d_i with the same d_o the focal point must be larger. You can test this with sample numbers if you don't see it at first.

1983B5.

a)



b) The image is on the other side of the mirror, it is not projectable, it is virtual.

c)
$1/f = 1/d_o + 1/d_i$
$1/20 = 1/15 + 1/d_i$ … $d_i = -60$ cm.

d)
$M = -d_i / d_o$ … $M = -(-60)/15 = 4$
$M = h_i / h_o$ … $4 = h_i / 3$ cm … $h_i = 12$ cm

1984B5.

a) $c = f\lambda$ … $3\text{x}10^8 = f(6\text{x}10^{-7})$ … $f = 5\text{x}10^{14}$ Hz.

b) $n_1 \lambda_1 = n_2 \lambda_2$ … $(1)(6\text{x}10^{-7}) = (1.25) = 4.8\text{x}10^{-7}$ m = 480 nm

c) The light is traveling to progressively more dense materials, so undergoes ½ λ phase shifts at both boundaries S_1 and S_2 essentially canceling out this phase shift (from flips). To get minimum intensity (destructive), the total phase shift from traveling in the film should be ½ λ_{film} so the film thickness should ¼ λ_{film} = ¼ 480 nm = 120 nm

d) Based on the same analysis above. To get maximum intensity (constructive) the total phase shift from traveling in the film should be 1 λ_{film}, so the film thickness should be ½ λ_{film} = ½ 480 nm = 240 nm

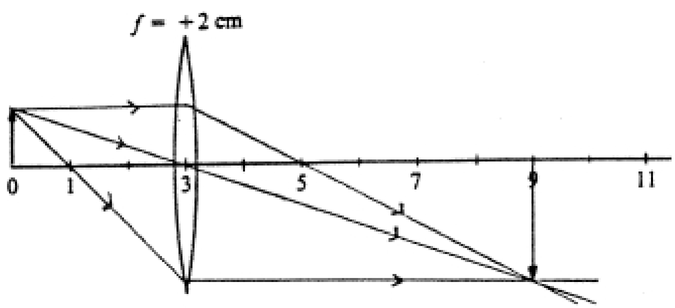
1985B5.
a) Simple application of the formula, $m\lambda = dx / L$ … $(1)(5x10^{-7}) = (4x10^{-4})(x) / (2)$ … $x = 2.5x10^{-3}$ m

b) i) $n_1 \lambda_1 = n_2 \lambda_2$ … $(1)(5x10^{-7}) = (1.3)\lambda_{water}$ … $\lambda_{water} = 3.85\ x10^{-7}$ m
ii) frequency does not change when changing mediums, same as air.
$c = f_{air} / \lambda_{air}$ … $3x10^8 = f_{air} / 5x10^{-7}$ … $f_{air} = 6x10^{14}$ Hz $= f_{water}$

c) Based on $m\lambda = dx / L$, since the λ is less, the x is less also which means the fringe spacing has decreased.

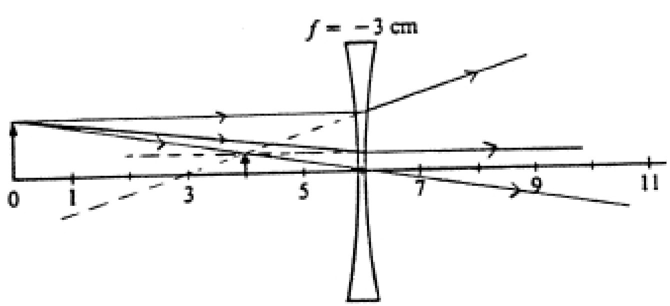
1986B6.

a)



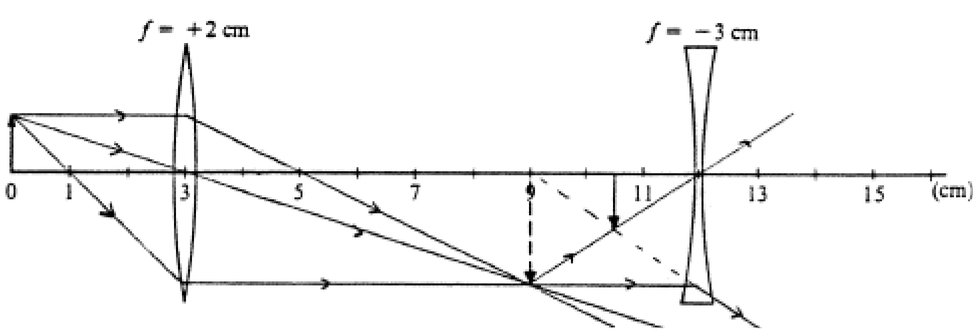
b) Find the magnification (= ratio of sizes), using the distances from above. $M = -d_i / d_o = -6 / 3 = -2$

c)



d) $1/f = 1/d_o + 1/d_i$ … $1/-3 = 1/6 + 1/d_i$ … $d_i = -2$ cm
e) Since d_i is – this is a virtual image

f)



1987B5.

a) Law of reflection, angle of incidence = angle of reflection. θ_3=30°

b) $n_i \sin \theta_i = n_r \sin \theta_r$, … (1.6) sin 30 = 1 sin θ_2 … θ_2 = 53.1°

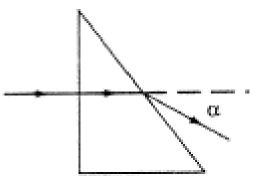
c) n = c /v (1.6) = 3x10^8 / v v = 1.875x10^8 m/s

d) First $c=f_{air}\lambda_{air}$ $n_1 \lambda_1 = n_2 \lambda_2$ … $n_{air} \lambda_{air} = n_{glass} \lambda_{glass}$ … $n_{air} (c/f_{air}) = n_g \lambda_g$ … $\lambda_g = 3.125\text{x}10^{-7}$ m

e) Determine critical angle, glass to air. $n_i \sin \theta_c = n_r \sin 90$ (1.6) sin θ_c = (1) θ_c = 38.68°
Any angle larger than 38.68° will cause total reflection.

1988B5.

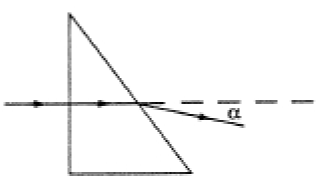
a)



b) $n_i \sin \theta_i = n_r \sin \theta_r$, … 1.5 sin (37) = 1 sin θ_r θ_r = 65° … therefore angle α shown above is 28°.

c) $n_i \sin \theta_i = n_r \sin \theta_r$, … n_i sin (37) = 1 n_i = 1.66, any n higher than this causes total internal.

d)



This ray would not totally reflect because by putting it in water we have reduced the difference between the n's meaning less bending and the limit of total internal has not be reached.

e) $n_i \sin \theta_i = n_r \sin \theta_r$, … (1.66) sin (37) = (1.33) sin θ_r … θ_r = 48.7° – 37° = 11.7°

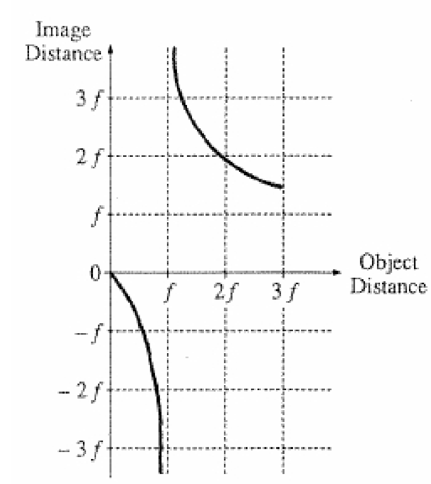
1989B5.

a) When placed outside of f, converging lenses make real images, this can be shown with the math below.

b) $1/f = 1/d_o + 1/d_i$ … $1/20 = 1/60 + 1/d_i$ … $d_i = 30$ cm.

c) $M = -d_i / d_o$ … $M = -(30)/60 = -0.5$

d) Based on the lens equation in b
virtual images (–) for d_o less than f.
undefined at f, approaches infinity.
d_i approaches f as d_o becomes large. →



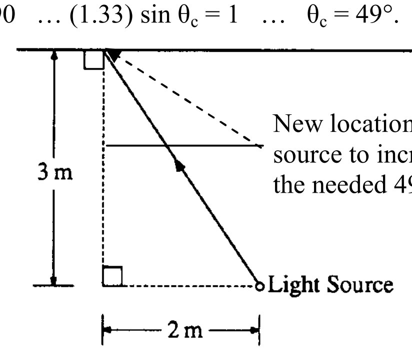
e) Based on $n_i \sin\theta_i = n_r \sin\theta_r$, snells law, by increasing the index of refraction, the refraction angle increased (more bending) which would move the focal point closer. This can be seen by looking at horizontal rays that bend through the focal point. These rays would bend more making the focal point closer (smaller f)

1990B6.

a) The reflected angle is the same as the angle of incidence which can be found using the geometry.
$\tan\theta = o/a = 2/3$ … $\theta = 34°$.

b) $n_i \sin\theta_i = n_r \sin\theta_r$ … $(1.33)\sin(34°) = (1)\,\theta_r$ … $\theta_r = 48°$.

c) We need to find the critical angle first … $n_i \sin\theta_c = n_r \sin 90$ … $(1.33)\sin\theta_c = 1$ … $\theta_c = 49°$.
Keeping the light source at the same horizontal distance away (2m) we have to raise up the light source (decreasing the 3m depth) until the we reach a point where the new depth and the 2m horizontal side of that triangle reach a 49° angle



New location of light source to increase θ_i to the needed 49°

Using geometry. $\tan\theta = o/a$
$\tan(49) = 2 / y_{new}$ → $y_{new} = 1.8$ m

d) Light travels from less n, to more n, to less n. A 180° (½ λ) phase shift will happen at the air–oil boundary only.

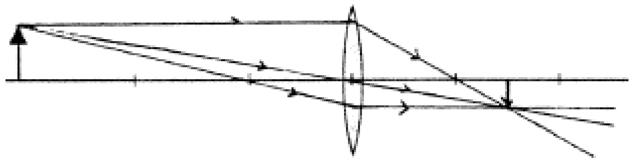
e) Based on the ½ λ phase shift air–oil, we need to create and additional ½ λ, or 1½ λ, or 2 ½ λ … phase shift from traveling in the oil to create maximum (constructive) intensities. To do this, oil thicknesses of $t = 1/4\,\lambda_{oil}$, $3/4\,\lambda_{oil}$, $5/4\,\lambda_{oil}$ … can be used. For an oil thickness of 100 nm (as given), these correspond to wavelength in the oil of 400 nm, 133.33 nm, 80 nm …

Now we have to convert these oil wavelengths to air wavelengths using $n_1 \lambda_1 = n_2 \lambda_2$ …
$n_{air} \lambda_{air} = n_{film} \lambda_{film}$ … $(1)(\lambda_{air}) = (1.5)(400)$ … $\lambda_{air} = 600$ nm. … repeating for the other λ's and we get possible air wavelengths of: 600 nm, 200 nm, 120 nm …

Since the visible spectrum in air ranges between 400–700 nm, only the 600 nm λ qualifies.

1992B6.

a)

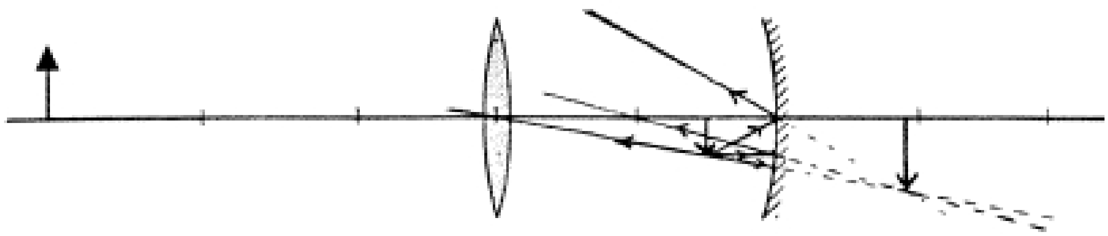


b) i) $1/f = 1/d_o + 1/d_i$ … $1/15 = 1/45 + 1/d_i$ … $d_i = 22.5$ cm.

ii) $M = -d_i / d_o$ … $M = -(22.5)/45 = -0.5$ … $M = h_i / h_o$ … $-0.5 = h_i / 8$ cm … $h_i = -4$ cm

c) As describe in MC section question 18, this would cause the image to dim only.

d)



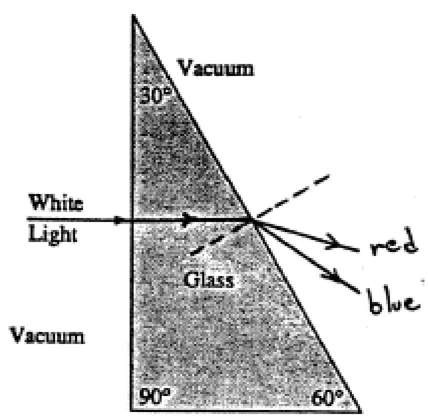
1993B4.

a) $n = c / v$ … $1.6 = 3x10^8 / v$ … $v = 1.9x10^8$ m/s

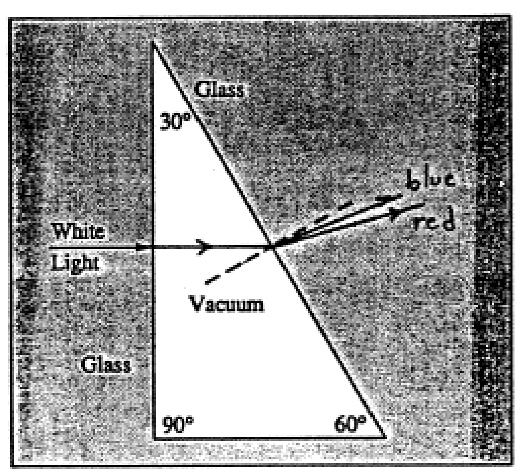
b) $n_1 \lambda_1 = n_2 \lambda_2$ … $(1)(700) = (1.5) \lambda_{glass(R)}$ … $\lambda_{glass(R)} = 466.67$ nm

c) Frequency in glass = frequency in air … $c = f \lambda$ … $3x10^8 = f (700x10^{-9}$ m) $f = 4.3x10^{-14}$ Hz

d)



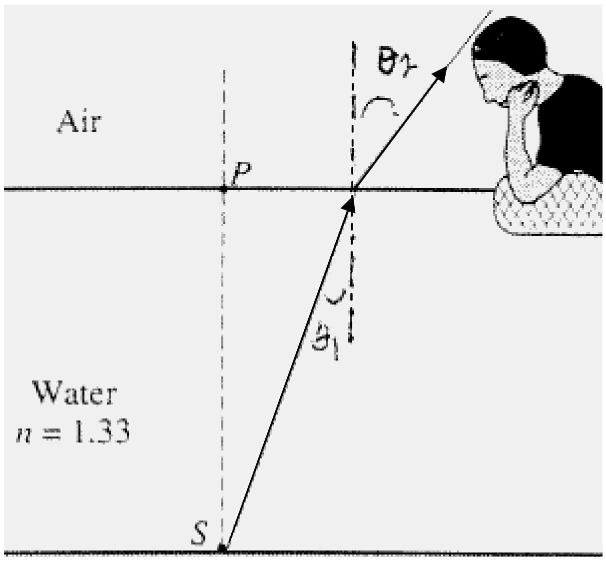
e)



1994B5.

a) $n = c/v$ … $1.33 = 3x10^8 / v$ … $v_{water} = 2.26x10^8$ m/s

b)



c) $n_i \sin \theta_c = n_r \sin 90$ … $(1.33) \sin \theta_c = (1)$ … $\theta_c = 48.8°$

d) $1/f = 1/d_o + 1/d_i$ … $1/10 = 1/20 + 1/d_i$ … $d_i = 20$ cm.
Looking at the diagram, this real image is formed 20 cm measured from the lens location. From the bottom of the pool, this image would be 40 cm above the bottom.

e) i) For an index of refraction equal to the lens, the lens is basically non–existent. There will be no bending of the light as at passes through the lens so no image will be formed
ii) By decreasing the difference in indices of refraction between the lens and surrounding substance, there will be less bending as the light passes through the lens. This will move the focal point farther away from the lens and the image location farther from the lens as well.

1996B3.

All portions of this problem have been done in the physical optics section besides d-i highlighted in bold,

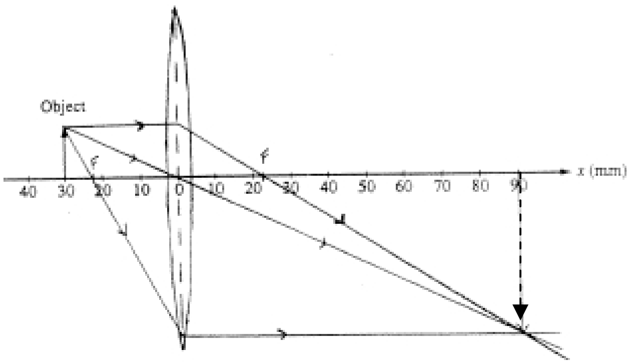
d) i Based on $n_1 \lambda_1 = n_2 \lambda_2$ … $n_{air} \lambda_{air} = n_{water} \lambda_{water}$. The λ_{water} is less in comparison to the air. So the λ has been decreased. In the equation $m \lambda = d x / L$, for decreased λ there will be decreased x, which means the location of spots is smaller, compressing the pattern.

1997B5.

a) The object is located in front of the lens (to the left). The image is located behind the lens (to the right). That means this is a real image, which can only be created by a converging lens.

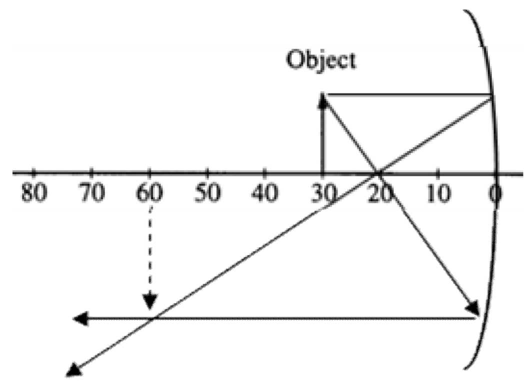
b) $1/f = 1/d_o + 1/d_i$ … $1/f = 1/30 + 1/90$ … $f = 22.5$ mm

c)



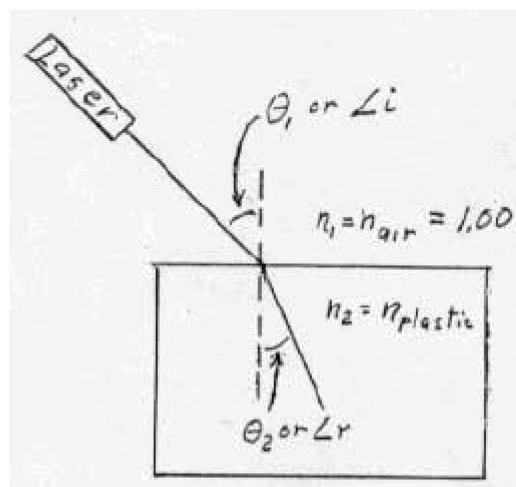
d) Real, Larger, Inverted.

e)



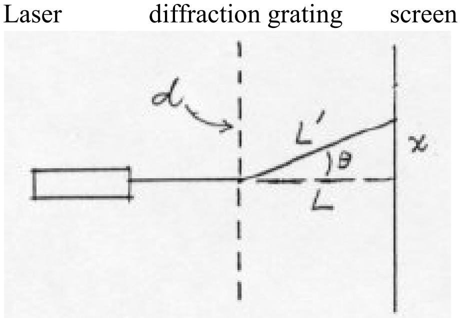
1999B6.

a) Place the laser on the table so that the beam will travel along the white screen placed on the tabletop. Locate the plastic block so that the light enters it at an angle to the normal to the surface of the plastic. Draw a line representing the surface of the block and the incident ray. Mark where the ray exits the block and remove the block. Draw a ray from the exit point back to the normal and incident ray. Measure the angle of incidence and the angle of refraction. Use snell's law with the index of air=1 to calculate the index for the plastic.



b)

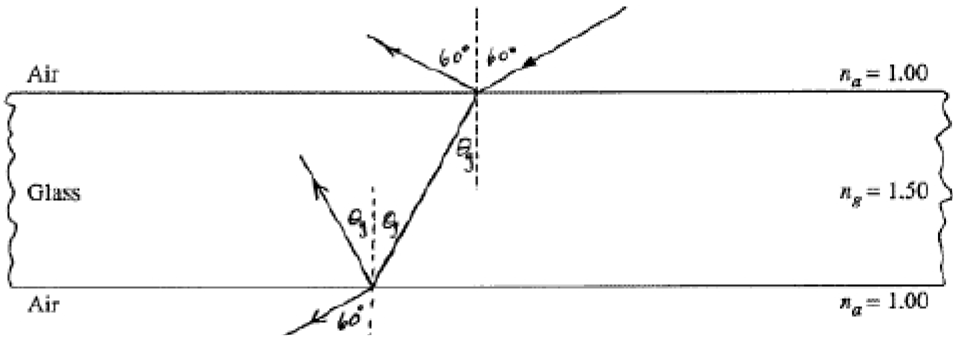
Laser diffraction grating screen



Using mλ = d sin θ. Measure x and L to the first bright spot and determine the angle θ with trig. m=1 for the first bright spot, then plug into the equation and solve for the wavelength. The assumption of d<<L is not really an assumption but an experimental parameter to properly use the equation.

2000B4.

a)



$n_i \sin \theta_i = n_r \sin \theta_r$ … $(1) \sin (60) = 1.5 \sin \theta_g$ … $\theta_g = 35.3°$

b) i) $c = f\lambda$ … $3\text{x}10^8 = f(5.25\text{x}10^{-7})$ … $f = 5.71\text{x}10^{14}$ Hz.

ii) frequency does not change when it enters the film, same as air … $f = 5.71\text{x}10^{14}$ Hz

iii) $n_1 \lambda_1 = n_2 \lambda_2$ … $n_{air} \lambda_{air} = n_{film} \lambda_{film}$ … $(1)(525) = (1.38) \lambda_{film}$ … $\lambda_{film} = 380$ nm.

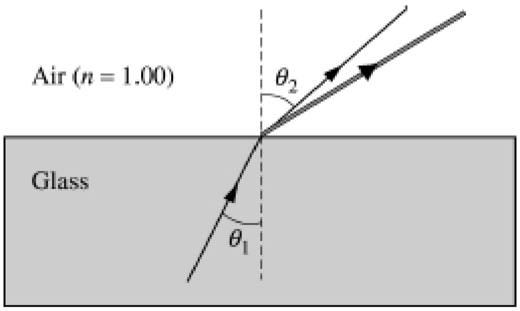
iv) To see the green reflection, you would need to have constructive interference from the film. As the light travels from the air to film to glass, it undergoes a ½ λ phase shift at each boundary. These two phase shifts essentially cancel each other out to get zero phase shift from the flips. To produce constructive interference, a total of one wavelength needs to be covered from traveling in the film. This requires a film thickness of ½ of the wavelength in the film. $t = ½ \lambda_{film} = ½ (380) = 190$ nm.

2001B4.

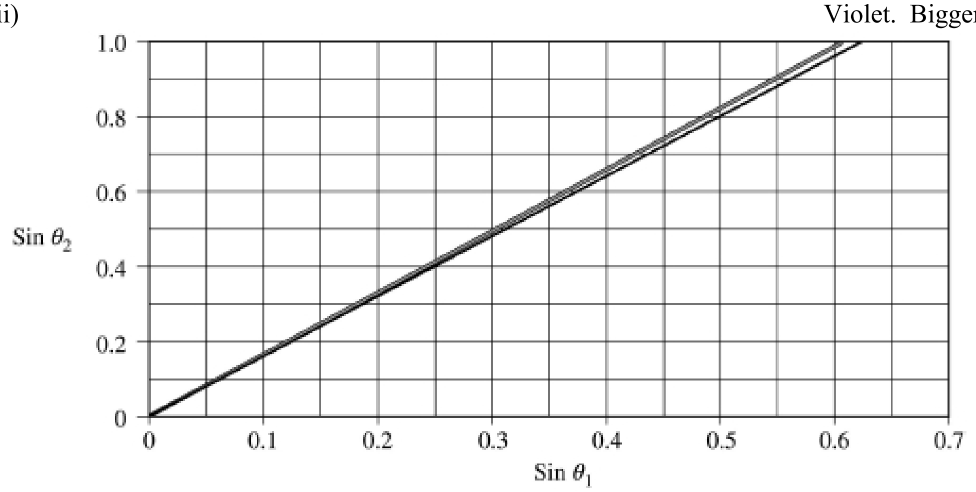
a) From snells law. $n_i \sin\theta_i = n_r \sin\theta_r$ …
$n_g \sin\theta_1 = n_{air} \sin\theta_2$ … $n_{glass} = \sin\theta_2 / \sin\theta_1$ = slope of graph. 0.8/0.5 = 1.6

b) i) $c = f\lambda$ … $3x10^8 = f\,(6.75x10^{-7})$ … $f = 4.44x10^{14}$ Hz.
ii) $n = c/v$ … $(1.6) = 3x10^8 / v$ … $v = 1.88x10^{8\ m/s}$
iii) $n_1 \lambda_1 = n_2 \lambda_2$ … $(1)(675nm)=(1.6)\lambda_{glass}$ … λ_{glass} = 422 nm

c) i. Violet. Bigger difference in n's, more θ_2



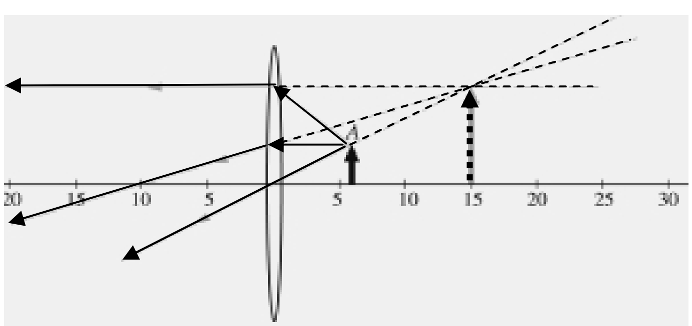
ii) Violet. Bigger n = bigger slope.



d) $n_i \sin\theta_c = n_r \sin 90$ … $(1.66) \sin\theta_c = 1$ … $\theta_c = 37°$.

2002B4.

a)



b) This object is on the same side of the lens and not projectable. It is virtual. The math below proves this ($-d_i$)

c) $1/f = 1/d_o + 1/d_i$ … $1/10 = 1/6 + 1/d_i$ … $d_i = -15$ cm.

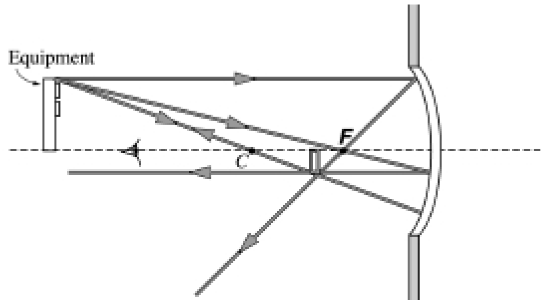
d) $M = -d_i / d_o$ … $M = -(-15)/6 = 2.5$

e) Redo the math. We get $d_i = +20$ cm, $M = -1$ … So the image is real (on the other side of the lens), is the same size as the object and is inverted.

2002B4B.

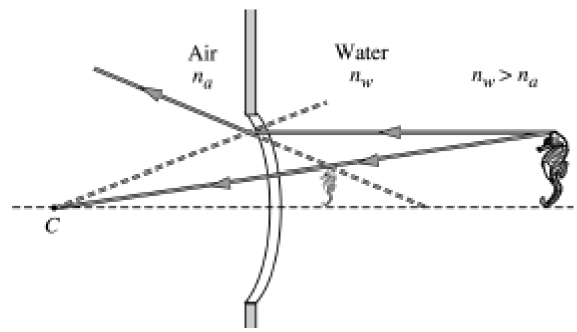
a) The focal point is half of the radius of curvature … r/2

b)



c) Image is Inverted, Real, Smaller.

d) Very Tricky. This is not a normal lens question. Since the glass of the window has the same index as the water, it is basically just a one sided lens with no front side (front side being the right) and only bends on the way into air but there is no bending when moving from water to glass because the glass–water boundaries are at the same index. Since its not a thin lens, the thin lens rules don't apply the same. We draw two rays simply based on the laws of refraction.



The ray towards C hits the lens at 0° and would travel straight through. The horizontal ray drawn above refracts at the water–air interface at an unknown angle that we approximate above to get a rough idea . We teachers, as authors of this solution guide, feel this part of the question is a bit nutty.

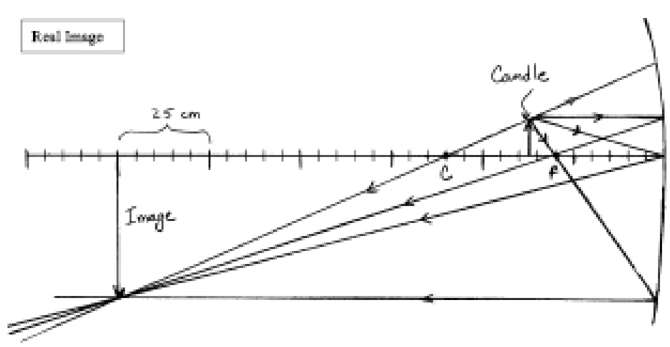
The image formed is upright, virtual and smaller.

2003B4.

a) Place the mirror at one end of the bench and the candle more than 30 cm from the mirror. Place the screen out beyond the candle and reposition it to get an image. Measure the height of the image. Reposition candle and screen until image height is four times object height

b) We need a meterstick/ruler and the screen in the holder for this first part.

c)

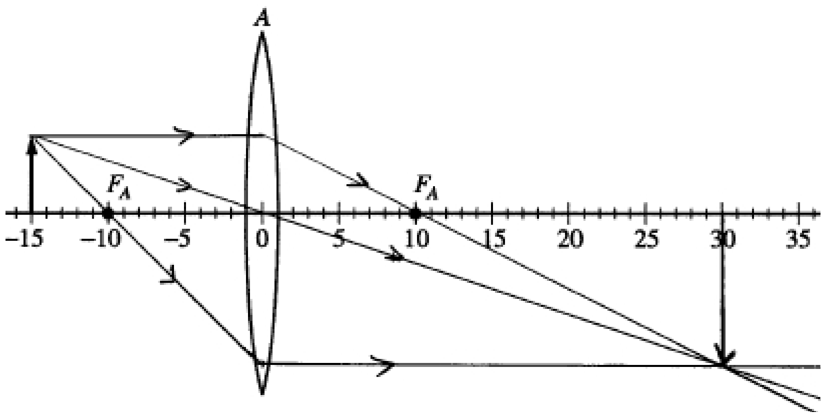


d) The image is inverted, larger and real.

e) This student may have added a lens to the experiment which would require a different candle location to produce the 4x magnification. Or they may have measured a virtual image which also would be a different location.

B2003B3.

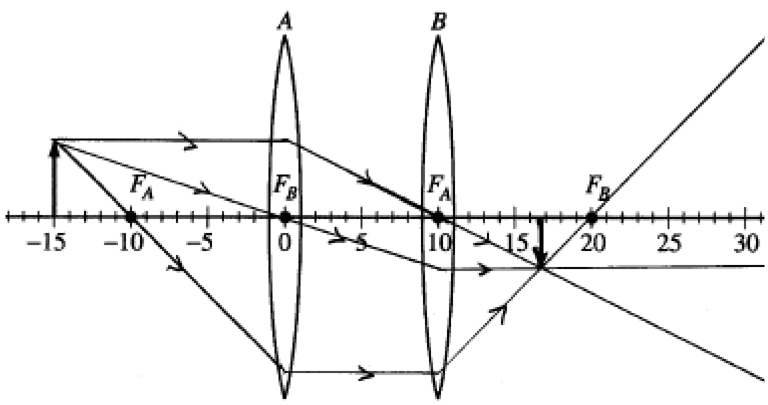
a)



b) $1/f = 1/d_o + 1/d_i$ … $1/10 = 1/15 + 1/d_i$ … $d_i = 30$ cm.

c) $M = -\,d_i / d_o$ … $M = (-30)/15 = -2$ … $M = h_i / h_o$ … $-2 = h_i / 5$ cm … $h_i = -\,10$ cm

d)



Mathematically: The image location for the first lens that we found in part 'b' (30cm from lens A), becomes the object for the second lens. Since this 'pre–image' would form on the other side of lens B, in relation to where the light originated from, and it is to be used as the object distance, the only way to account for this is to make the object distance d_o negative for the second lens (this is one of the few times this is possible). Based on the location of the second lens, the d_o for that lens equation would be – 20 cm. Solving that equation results in $d_i = +\,6.7$ cm (measured from lens B) which means it is located at 16.7 cm on the scale shown.

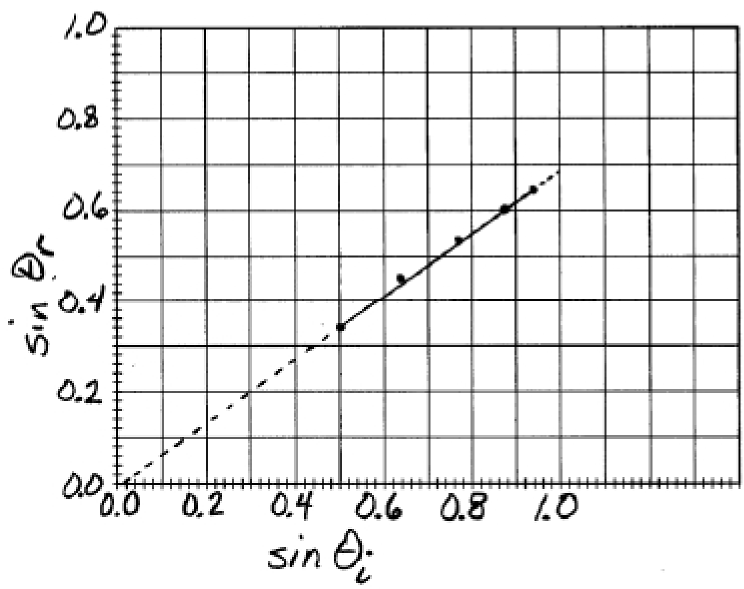
This image is smaller, real, inverted.

2006B4.

a)

Trial	θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
1	30°	20°	0.50	0.34
2	40°	27°	0.64	0.45
3	50°	32°	0.77	0.53
4	60°	37°	0.87	0.60
5	70°	40°	0.94	0.64

b)



c) From snells law. $n_i \sin\theta_i = n_r \sin\theta_r$ … $n_{air} \sin\theta_i = n_{glass} \sin\theta_r$ … $n_{glass} = \sin\theta_i / \sin\theta_r$

For the graph we have, this would be the inverse slope → 1 / slope. Slope = 0.67 … 1/0.67 … $n_{glass} = 1.5$

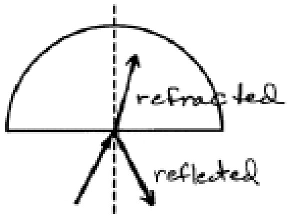
d) ½ λ phase shifts happen when entering a more optically dense material. So only air–oil does a phase shift happen.

e) First we need to know the wavelength in the film (oil) … $n_1 \lambda_1 = n_2 \lambda_2$ … $(1)(600) = (1.43)\lambda_{oil}$ … $\lambda_{oil} = 420$ nm

Since there is already a ½ λ phase shift from the boundary flip, we need a total extra phase shift of ½ λ from traveling in the film to produce constructive interference (maximum). For this, ¼ λ_{oil} is required = 105 nm.

B2006B4.

a) i.



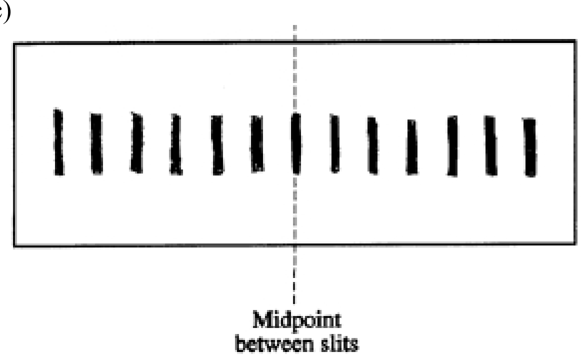
ii) $n_i \sin\theta_i = n_r \sin\theta_r$ … (1) sin(27) = 1.51 sin θ_r … θ_r = 17.5°.

iii) n = c / v … 1.51 = $3\text{x}10^8$ / v … v = $1.99\text{x}10^8$ m/s

iv) $n_1 \lambda_1 = n_2 \lambda_2$ … (1)(650 nm) = (1.51) λ_2 … $\lambda_{plastic}$ = 430 nm

b) The angle of reflection is the same because the incoming angle is still the same and the law of reflection still applies.
The angle of refraction is larger because based on snells law, a larger n_r requires a smaller θ_r for same n_i & θ_i. Based on the diagram above, we can see this means the light has bent more to make a smaller θ_r

c)

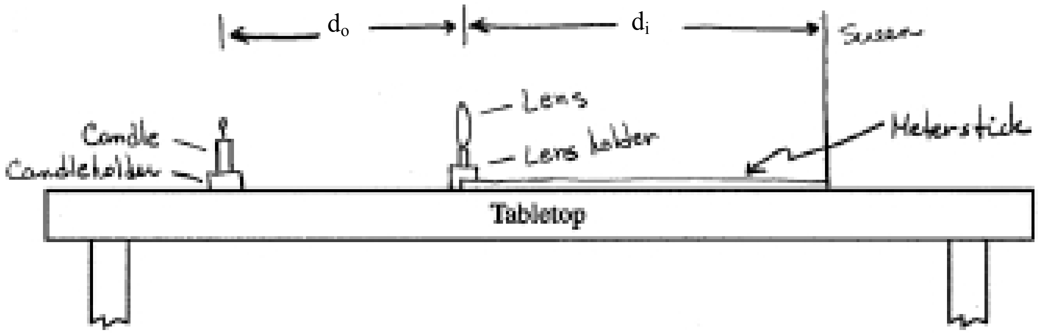


d) m λ = d x / L … $(1)(450\text{x}10^{-9}) = (0.15\text{x}10^{-3})$ x / (1.4) … x = 4.2 $\text{x}10^{-3}$ m

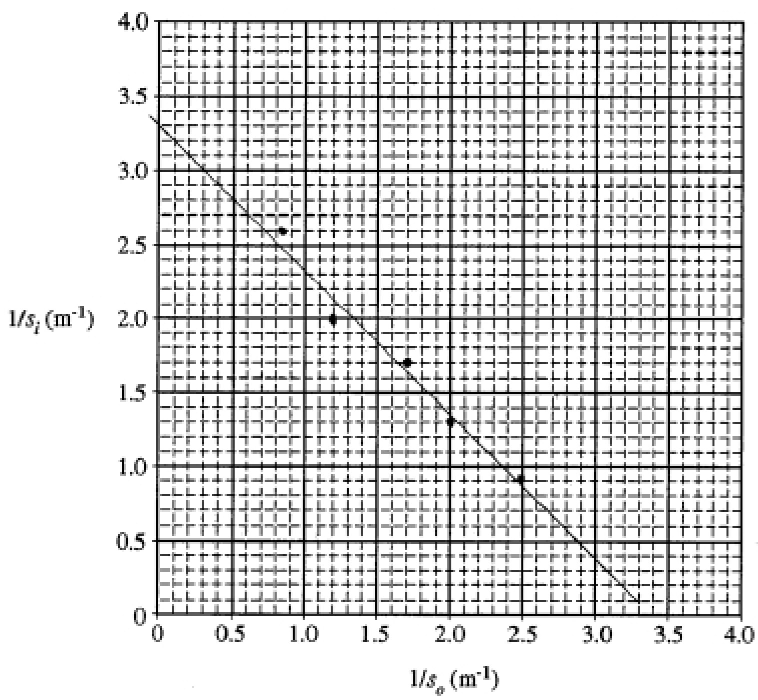
2007B6.

a) Estimate the focal length by focusing the image of the tree on a screen, the distance between the image and the lens is the focal length since the distant rays are assumed horizontal.

b&c)



d)



From the equation … $1/f = 1/d_o + 1/d_i$ = $1/f = 1/s_o + 1/s_i$ … we rearrange this equation to be of the form y=mx+b

Y = mx + b

$(1/s_i) = (1/s_i) + (1/f)$

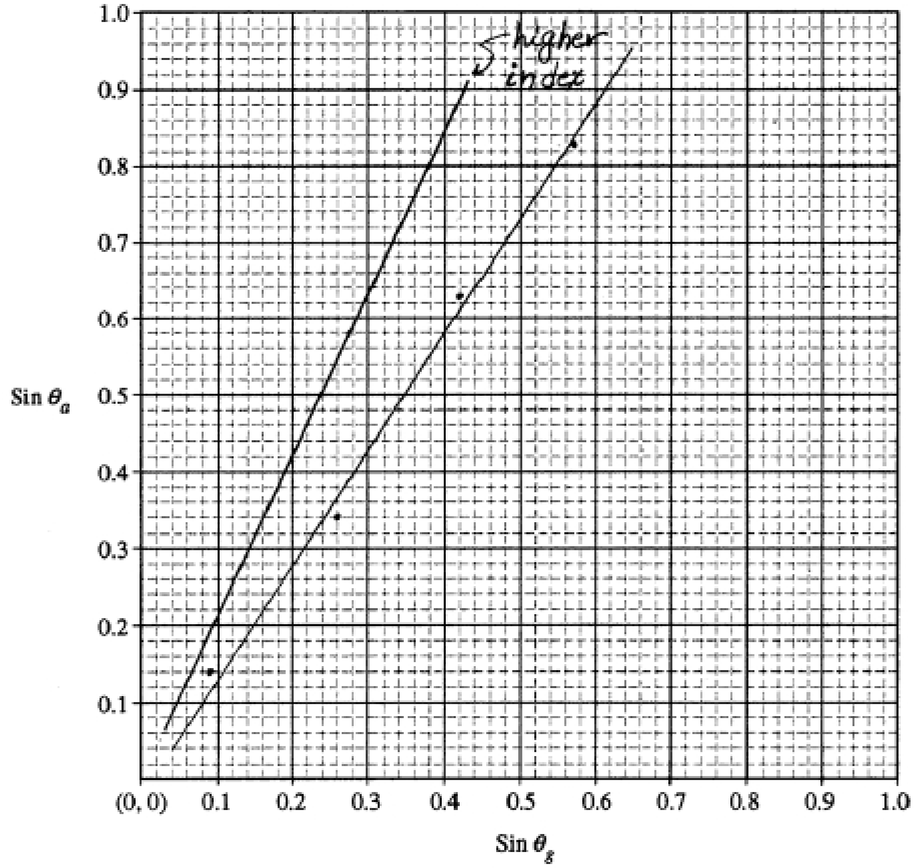
So the 1/f is the y intercept from the graph

$3.3 = 1/f \rightarrow f = 0.3$

Or you could pick a point on the line and plug in for $1/s_i$ and $1/s_o$ to solve for 1/f

B2007B6.

a) & d) .. a is the lower slope line



b) From Snells law, the slope of this graph is n_{glass} = 1.5

c) From $n_{glass} \sin \theta_c = n_{air} \sin \theta_{air}$ … we want to use the point where $\sin \theta_{air} = \sin 90 = 1$. This point will correspond to the related angle in the glass and since it's the critical point, this will allow you to find θ_c

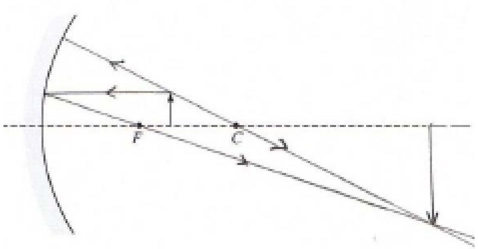
So we find $\sin \theta_a = 1$ from the graph and find the corresponding value of $\sin \theta_{glass}$ that goes with it.

Extending the lower slope line up to 1.0, we get a $\sin \theta_g$ value and then set that value = $\sin \theta_g$ and solve for θ which is the critical angle.

d) On graph.

2008B6.

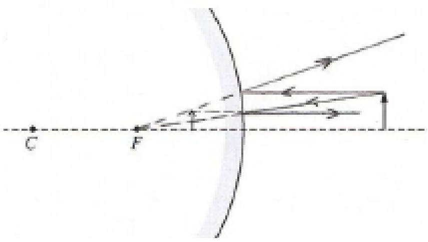
a)



b) The image is on the same side as the object and is projectable thus real.

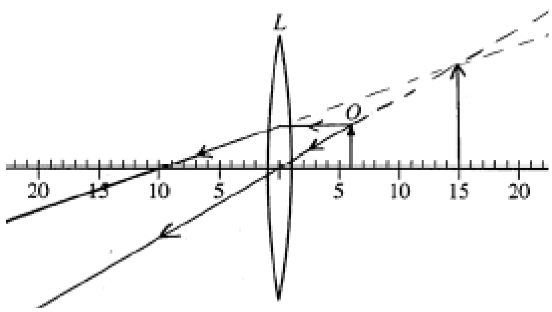
c) $1/f = 1/d_o + 1/d_i$ … $1/6 = 1/8 + 1/d_i$ … $d_i = 24$ cm

d) The converging mirror made a larger size object. The diverging mirror always makes the same type of image regardless of where the object is placed. It always makes **smaller**, upright, virtual images. This can be proved mathematically or with a ray diagram for this situation.



B2008B6.

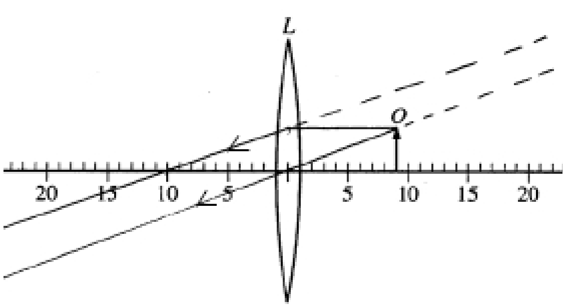
a)



b) i&ii. This image is virtual because it is on the same side as the object and is not projectable, this can also be proven mathematically as shown below.

c) $1/f = 1/d_o + 1/d_i$ … $1/10 = 1/6 + 1/d_i$ … $d_i = -15$ cm

d)



This image is very close to the focal point. The rays will intersect further away and make a much larger image as shown in the ray diagram. This could also be proved mathematically comparing the magnification before (2.5) to the magnification after (10).

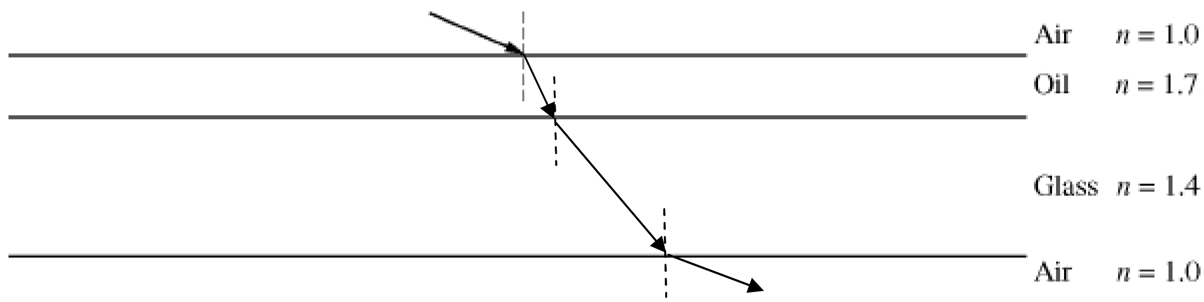
B2009B5.

a) $n = c / v$ … $1.7 = 3 \times 10^8 / v$ … $v = 1.76 \times 10^8$ m/s

b) $n_1 \lambda_1 = n_2 \lambda_2$ … $n_{air} \lambda_{air} = n_{oil} \lambda_{oil}$ … $(1)(520 \text{ nm}) = (1.7) \lambda_{oil}$ … $\lambda_{oil} = 306$ nm

c) To see the green light max intensity, we need constructive interference in the film for that green light wavelength. As the light travels from air–oil, it undergoes a ½ λ phase shift, but there is no phase shift at the second boundary. In order to produce constructive interference, we need to produce a total extra ½ λ phase shift from traveling in the film thickness. This requires the film thickness be $\frac{1}{4} \lambda_{oil} = \frac{1}{4}(306) = 76.5$ nm

d) Only the refracted ray is shown. We assume total internal reflection does not occur based on problem statements.



2009B5.

a) $c = f\lambda$ … $3 \times 10^8 = f(550 \times 10^{-9})$ … $f = 5.45 \times 10^{14}$ Hz.

b) $m\lambda = d x_1 / L$ … $(0.5)(550 \times 10^{-9}) = (1.8 \times 10^{-5}) x / 2.2$ $x_1 = 0.0336$ m first dark spot
$m\lambda = d x_2 / L$ … $(1.5)(550 \times 10^{-9}) = (1.8 \times 10^{-5}) x / 2.2$ $x_2 = 0.101$ m second dark spot

Distance between spots = .067 m

c) frequency does not change when changing mediums. The frequency is still 5.45×10^{14} Hz.

d) In the fluid, the larger n makes the wavelength smaller based on $n_{air} \lambda_{air} = n_{fluid} \lambda_{fluid}$. From $m\lambda = d x / L$, the reduced λ causes the x to decrease as well.

Supplemental.

a) i. $c = f\lambda$ … $3 \times 10^8 = f(520 \text{ nm})$ … $f = 5.77 \times 10^{14}$ Hz.
ii. frequency in film is the same as in the air, it doesn't change between mediums = 5.77×10^{14} Hz
iii. $n_1 \lambda_1 = n_2 \lambda_2$ … $n_{air} \lambda_{air} = n_{film} \lambda_{film}$ … $(1)(520 \text{ nm}) = (1.4)\lambda_{oil}$ … $\lambda_{oil} = 371$ nm

b) There will be ½ λ phase shifts at each boundary essentially canceling out each 'flip'. To make constructive interference, a total of 1 λ of phase shift is needed from traveling in the film and this requires the thickness of the film to be $\frac{1}{2} \lambda_{film} = \frac{1}{2}(371) = 186$ nm

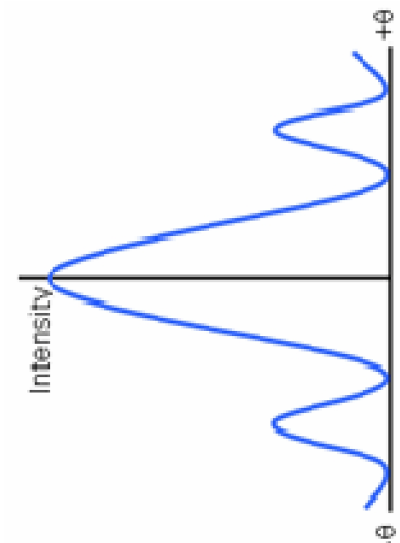
c) As the angle changes, the effective thickness of the film changes as well since the rays travel at angles in the film. The white light source has all frequency colors in it, and different thicknesses traveled will cause different constructive interference with different wavelength colors of light. (This is why a soap bubble has many colors reflected in it. The variation in thickness along the bubble makes different wavelength constructive in different regions)

SECTION B – Physical Optics

1975B4.

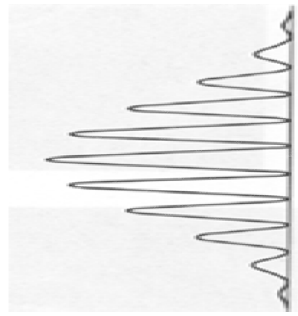
a) One slit

wider



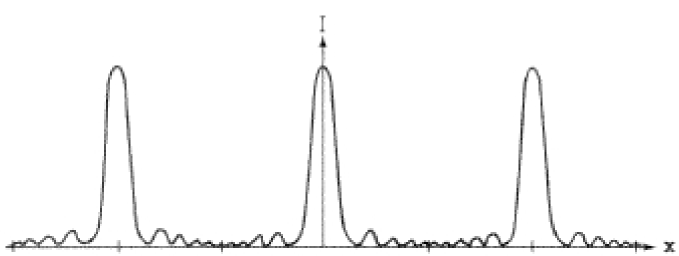
b) Two slits

more narrow



1980B4.

a) Change double slits to diffraction grating

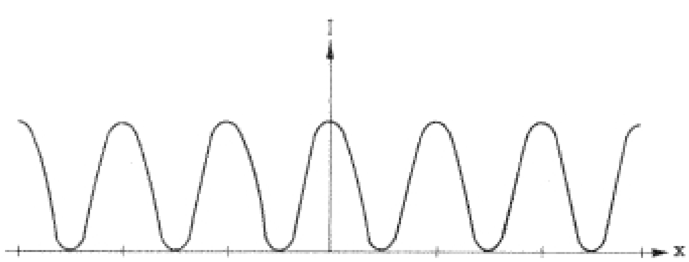


Notable features:
1) Maxima at same locations as before ($m\,\lambda = d \sin\theta$) would give same results

2) Maxima more narrow and well defined

3) Minimal intensity light in–between well defined maxima's

b) Spacing "d" of two slit arrangement doubled … $m\,\lambda = d \sin\theta$ … 2x d → ½ the angle (for small angles)



First maxima occurs at half the distance away as before.

Note: This diagram shows equal intensity spots, in reality the intensity of the spots should diminish slightly as moving away from center.

1985B5.

a) Simple application of the formula, m λ = d x / L … $(1)(5\text{x}10^{-7}) = (4\text{x}10^{-4})(x) / (2)$ … $x = 2.5\text{x}10^{-3}$ m

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1991B6.

a) m λ_B = d x / L … $(1)\ (5.5\text{x}10^{-7}) = d\ (1.2\text{x}10^{-2}) / (0.85)$ $d = 3.9\text{x}10^{-5}$ m

b) m λ_a = d x / L … $(1)\ (4.4\text{x}10^{-7}) = (3.9\text{x}10^{-5})\ x / (0.85)$ $x = 9.6\text{x}10^{-3}$ m

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1996B3.

a) The fact that light interferes means it's a wave (this will be discussed more in the modern physics topic)

b) Looking at the intensity pattern, P is the second point of zero intensity which means it's the 2nd dark spot (m=1.5). Using Path Diff = mλ … m λ = d x / L … path diff = $(2\text{x}10^{-3})\ (1.8\text{x}10^{-3}) / 5$ … path diff = $7.2\text{x}10^{-7}$ m

c) Path Diff = mλ … $7.2\text{x}10^{-7} = 1.5\ \lambda$ … $\lambda = 4.8\text{x}10^{-7}$ m

d) ii) Covering a slit makes this a single slit pattern. In the single slit, m=1 becomes the first dark region (the end of the central bright spot) instead of m=0.5 being the end of the central bright spot. All of the other integer m's also become dark spot locations. The effect of this is to make the central max wider and widen the pattern. Additionally, in single slit diffraction, the intensities generally lose intensity more rapidly when moving away from the center.

iii) Increasing d. Based on mλ = d x / L, this would make x less so would compress the pattern.

1998B7.

a) Diffraction grating: Since the screen distance is 1 m and the first order line is at 0.428 m, the angle is not small and the small angle approximation cannot be used. Instead we find the angle with tan θ and use mλ = d sin θ. First find d. d = 600 lines / mm = 1/600 mm / line = 0.00167 mm / line = $1.67\text{x}10^{-6}$ m / line.

tan θ = o/a … tan θ = 0.428 / 1 … $\theta = 23°$ … Then, mλ = d sin θ … $(1)\ \lambda = (1.67\text{x}10^{-6})\sin 23°$
$\lambda = 6.57\text{x}10^{-7}$ m = 657 nm

c) Referring to the calculation of d above .. d = 1/800 mm / line which is a smaller d value. Less d means sin θ must increase so the angle is larger and the location of the line would be further out.

2004B4.

Often with speakers, none of the approximation work and we simply have to work with the distances to find the path difference, because the angle to the observer is not small and also the spacing of the speakers is also not small. In this example, the spacing of the speakers is relatively small in comparison to the distance away L, so we can use m λ = d sin θ. However the location of point Q is unclear so we will not assume that the small angle approximation (x/L) would work.

a) Simple. v = f λ … 343 = 2500 f … λ = 0.1372 m

b) Determine θ … mλ = d sin θ … (0.5) (0.1372) = (0.75) sin θ … θ = 5.25° (small enough to have used x/L)

Now find Y … tan θ = o / a … tan (5.25) = Y / 5 … Y = 0.459 m

c) Another minimum, 'dark spot' (not dark since its sound), could be found at the same distance Y above point P on the opposite side. Or, still looking below P, you could use m = 1.5 and find the new value of Y.

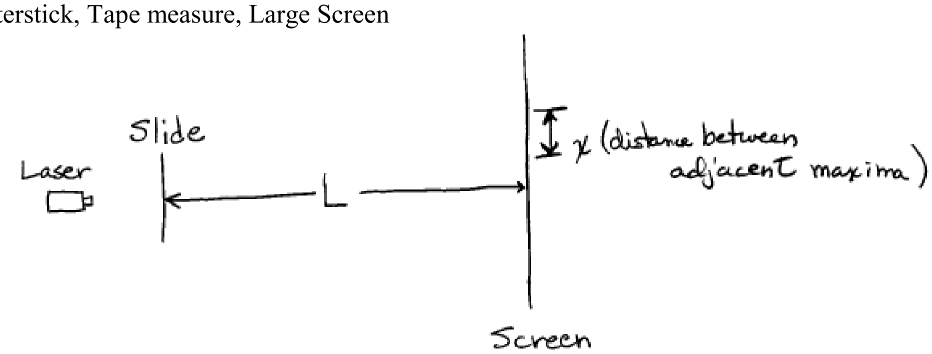
d) i) Based on the formulas and analysis from point b, it can clearly be see that decreasing d, would make angle θ increase, which would increase Y

ii) Since the speed of sound stays constant, increasing f, decreases the λ. Again from the formulas and analysis in part b we see that less λ means less θ and decreases the location Y.

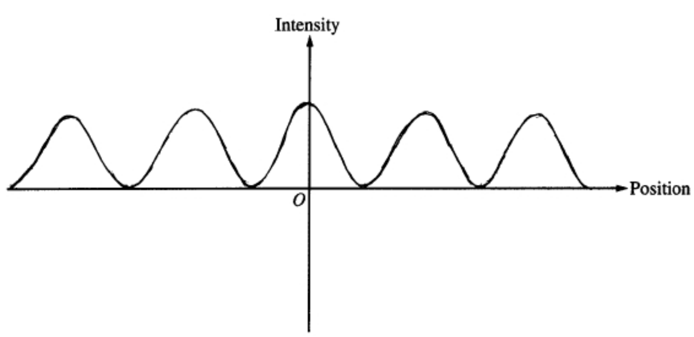
2005B4.

a) Meterstick, Tape measure, Large Screen

b)



c)



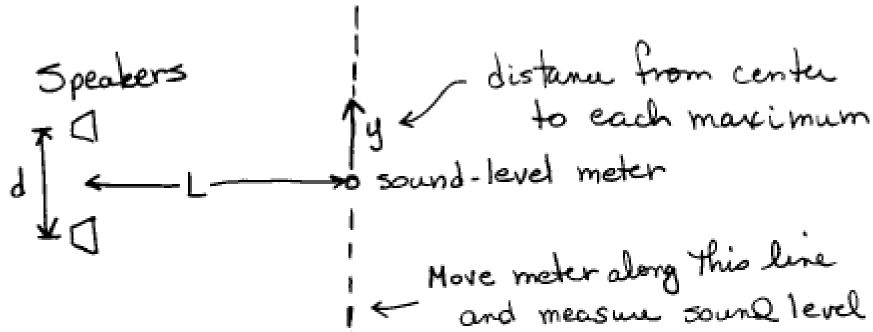
d) Set up the laser to shine on the slide, and set the screen far away on the other side of the slide. Measure the distance *L* from the slide to the screen with the tape measure. Use the ruler to measure the distance *x* between adjacent maxima.

e) With the values obtained above, plug into m λ = d x / L, with m = 1 for the first spot and other variables as defined above and the known λ of the laser used, solve for d. Assuming angle θ is small. It not, determine theta and use m λ = d sin θ

B2005B4. This is basically the same as 2005B4 but with sound.

a) Meterstick, tape measure, sound level meter

b)



c) Set the speakers a fixed distance *d* apart, pointing perpendicular to the line along which *d* is measured. Determine a line parallel to the speaker line and a distance *L* away. Use the sound meter to locate the maxima of the interference pattern along this line. Record the locations of these, y values, maxima along the line.

d) With the values obtained above, plug into $m\,\lambda = d\,x / L$, with $m = 1$ for the first maxima and other variables as defined above to determine the λ of the sound. Assuming angle θ is small. It not, determine theta and use $m\,\lambda = d \sin\theta$. Then, with the λ plug into $v = f\,\lambda$ with v as speed of sound to determine f.

e) Decreasing frequency results in increasing wavelength for constant velocity. Based on $m\lambda = d\,x / L$, larger wavelength means a larger x value and thus the distance between successive maxima will increase.

2009B6.

a) $c = f\,\lambda$ … $3\text{x}10^{8} = f\,(550\text{x}10^{-9})$ … $f = 5.45\text{x}10^{14}$ Hz.

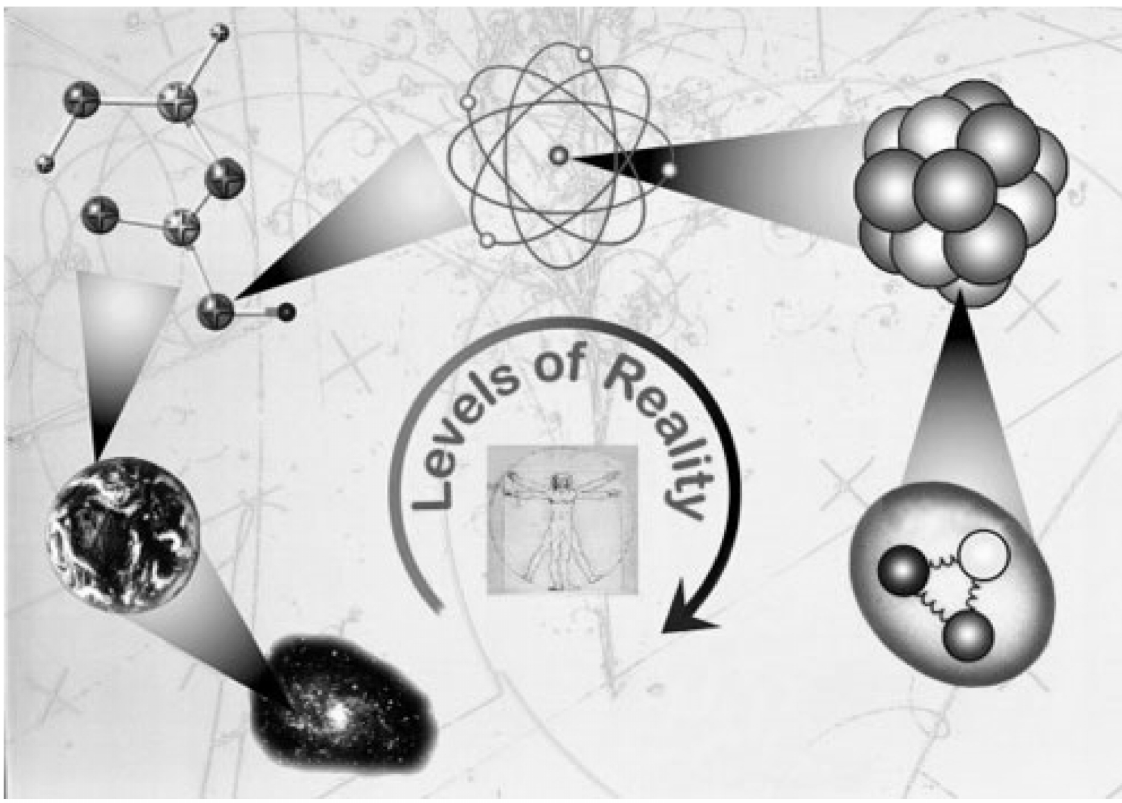
b) $m\,\lambda = d\,x_1 / L$ … $(0.5)\,(550\text{x}10^{-9}) = (1.8\text{x}10^{-5})\,x / 2.2$ $\qquad x_1 = 0.0336$ m first dark spot
$m\,\lambda = d\,x_2 / L$ … $(1.5)\,(550\text{x}10^{-9}) = (1.8\text{x}10^{-5})\,x / 2.2$ $\qquad x_2 = 0.101$ m second dark spot

Distance between spots = .067 m

Alternatively you could find the location if the first bright spot from center and conclude the spacing of consecutive bright and dark spots are equal so should all be spaced by this amount.

Chapter 18

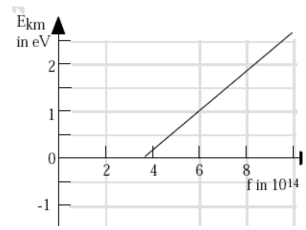
Modern Physics



SECTION A – Quantum Physics and Atom Models

1. An atomic particle of mass m moving at speed v is found to have wavelength λ. What is the wavelength of a second particle with three times the speed and twice the mass?
A) $3\lambda/2$ B) $2\lambda/3$ C) 6λ D) $\lambda/6$

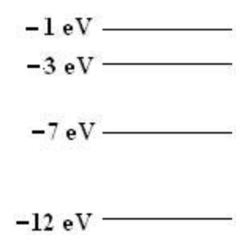
2. A student performs the photoelectric effect experiment and obtains the data depicted in the accompanying graph of E_{km} (maximum kinetic energy) of photoelectrons v. the frequency of the photons. What is the approximate work function of this material?
A) 1.5 eV B) 2.0 eV C) 2.7 eV D) 3.5 eV



3. According to the Bohr theory of the hydrogen atom, electrons starting in the 4th energy level and eventually ending up in the ground state, could produce a total of how many lines in the hydrogen spectra?
A) 3 B) 4 C) 5 D) 6

4. In the photoelectric effect experiment, a stopping potential of V_{stop} is needed when light of frequency f_o shines on the electron-emitting metal surface. If the metal surface on which the light shines is replaced with a new material that has half the work function, what is the new stopping potential, V_{new}, for light of frequency shining on it?
A) $V_{new} > 2V_{stop}$ B) $V_{new} = 2\ V_{stop}$ C) $V_{stop} < V_{new} < 2V_{stop}$ D) It is indeterminate from the given information

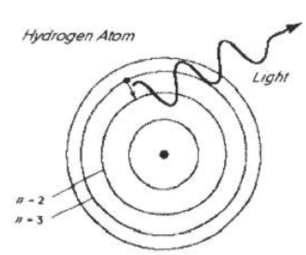
5. The diagram to the right shows the lowest four energy levels for an electron in a hypothetical atom. The electron is excited to the $-1\ eV$ level of the atom and transitions to the lowest energy state by emitting only two photons. Which of the following energies could not belong to either of the photons?
(A) 2 eV (B) 4 eV (C) 5 eV (D) 6 eV

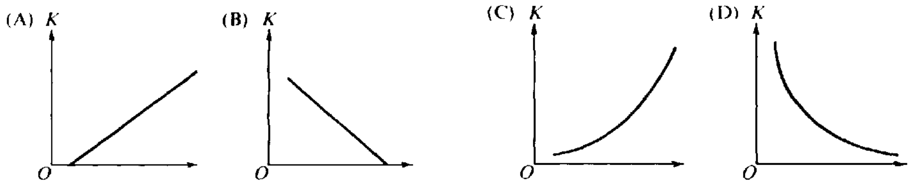


6. Monochromatic light falling on the surface of an active metal causes electrons to be ejected from the metallic surface with a maximum kinetic energy of E. What would happen to the maximum energy of the ejected electrons if the frequency of the light were doubled?
A) the maximum energy of the electrons would be ½ E
B) the maximum energy of the electrons would be ($\sqrt{2}$) E
C) the maximum energy of the electrons would be 2E
D) the maximum energy of the electrons would be greater than 2E

7. A very slow proton has its kinetic energy doubled. What happens to the protons corresponding de Broglie wavelength
A) the wavelength is decreased by a factor of $\sqrt{2}$
B) the wavelength is halved
C) the wavelength is increased by a factor of $\sqrt{2}$
D) the wavelength is doubled.

8. The diagram shows light being emitted due to a transition from the n=3 to the n=2 level of a hydrogen atom in the Bohr model. If the transition were from the n=3 to the n=1 level instead, the light emitted would have
A) lower frequency B) longer wavelength C) greater speed
D) greater momentum



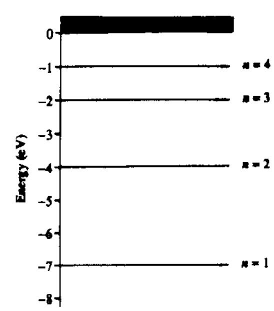


9. Which graph above best shows the maximum kinetic energy K of the photoelectrons as a function of the frequency of incident light?
   (A) A (B) B (C) C (D) D

10. Electrons that have been accelerated from rest through a potential difference of 150 volts have a de Broglie wavelength of approximately 1 Angstrom (10^{-10} meter). In order to obtain electrons whose de Broglie wavelength is 0.5 Angstrom (5×10^{-11} meter), what accelerating potential is required?
    (A) 37.5 V (B) 75 V (C) 300 V (D) 600 V

11. The energy level diagram is for a hypothetical atom. A gas of these atoms initially in the ground state is irradiated with photons having a continuous range of energies between 7 and 10 electron volts. One would expect photons of which of the following energies to be emitted from the gas?
    (A) 1, 2, and 3 eV only
    (B) 4, 5, and 9 eV only
    (C) 1, 3, 5, and 10 eV only
    (D) 1, 5, 7, and 10 eV only

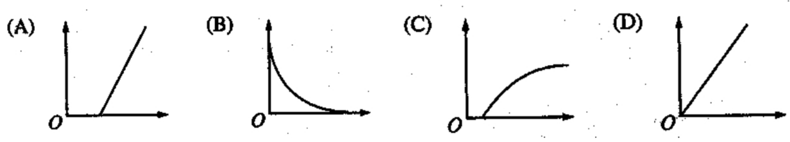
12. A hypothetical atom has four energy states as shown. Which of the following transitions will produce the photon with the longest wavelength?
    (A) n = 2 to n = 1
    (B) n = 3 to n = 1
    (C) n = 4 to n = 1
    (D) n = 4 to n = 3



13. In the Bohr model of the atom, the postulate stating that the orbital angular momentum of the electron is quantized can be interpreted in which of the following ways?
    (A) An integral number of electron wavelengths must fit into the electron's circular orbit.
    (B) Only one electron can exist in each possible electron state.
    (C) The atom is composed of a small, positively charged nucleus orbited by electrons.
    (D) An incident photon is completely absorbed when it causes an electron to move to a higher energy state.

14. If photons of light of frequency f have momentum p, photons of light of frequency $2f$ will have a momentum of
    (A) $2p$ (B) $\sqrt{2}p$ (C) $\frac{p}{\sqrt{2}}$ (D) ½ p

15. **Multiple Correct.** In an experiment, light of a particular wavelength is incident on a metal surface, and electrons are emitted from the surface as a result. To produce more electrons per unit time but with less kinetic energy per electron, the experimenter should do which of the following? Select two answers:
    (A) Increase the intensity of the light.
    (B) Decrease the intensity of the light.
    (C) Increase the wavelength of the light.
    (D) Decrease the wavelength of the light.



16. Which graph above shows the total photoelectric current versus the intensity of the light for a fixed frequency above the cutoff frequency?
    (A) A (B) B (C) C (D) D

17. A 50,000 W radio station transmits waves of wavelength 4 m. Which of the following is the best estimate of the number of photons it emits per second?
    (A) 10^{22} (B) 10^{30} (C) 10^{40} (D) 10^{56}

18. Two monochromatic light beams, one red and one green, have the same intensity and the same cross sectional area. How does the energy of each photon and the number of photons crossing a unit area per second in the red beam compare with those of the green beam?

Energy of Photon	Number of Photons Crossing Unit Area per Second
(A) Greater for red	Less for red
(B) Greater for red	Greater for red
(C) Less for red	Less for red
(D) Less for red	Greater for red

19. In an x-ray tube, electrons striking a target are brought to rest, causing x-rays to be emitted. In a particular x-ray tube, the maximum frequency of the emitted continuum x-ray spectrum is f_o. If the voltage across the tube is doubled, the maximum frequency is
    (A) $f_o/2$ (B) $f_o/\sqrt{2}$ (C) $\sqrt{2}\, f_o$ (D) $2f_o$

SECTION B – Nuclear Physics

1. A radioactive oxygen $^{15}O_8$ nucleus emits a positron and becomes
   A) $^{15}N_7$ B) $^{15}O_8$ C) $^{14}F_9$ D) $^{15}F_9$

2. A radon $^{220}Rn_{86}$ nucleus emits an alpha particle becomes a
   A) $^{216}Po_{84}$ B) $^{220}At_{85}$ C) $^{220}Rn_{86}$ D) $^{220}Fr_{87}$

3. A potassium $^{40}K_{19}$ nucleus emits a B^- and becomes:
   A) $^{36}Cl_{17}$ B) $^{40}Ar_{18}$ C) $^{40}K_{19}$ D) $^{40}Ca_{20}$

4. A photon with frequency f behaves as if it had a mass equal to
   A) hf / c^2 B) c^2 / hf C) fc^2 / h D) h / fc^2

5. What does the ? represent in the nuclear reaction $^2H_1 + {}^2H_1 \rightarrow {}^3He_2 + ?$
   A) a beta B) a gamma C) a neutron D) a proton

6. What does the ? represent in the nuclear reaction $^6Li_3 + ? \rightarrow {}^7Li_3$
   A) an alpha particle B) an electron C) a neutron D) a proton

7. The following equation is an example of what kind of nuclear reaction

$$^{235}U_{92} + {}^1n_0 \rightarrow {}^{133}Sb_{51} + {}^{99}Nb_{41} + 4\,({}^1n_0)$$

   A) fission B) fusion C) alpha decay D) beta decay

8. The following equation is an example of what kind of nuclear reaction

$$^{12}C_6 + {}^4He_2 \rightarrow {}^{16}O_8 + \text{energy}$$

A) fission B) fusion C) alpha decay D) beta decay

9. A nucleus of $^{235}U_{92}$ disintegrates to $^{207}Pb_{82}$ in about a billion years by emitting 7 alpha particles and x beta particles, where x is
A) 3 B) 4 C) 5 D) 6

10. The following nuclear reaction occurs:

$${}^4_2He + {}^9_4Be \rightarrow {}^{12}_6C + {}^A_ZX$$. What is ${}^A_ZX$?

A) a proton B) an electron C) a positron D) a neutron

11. A scientist claims to have perfected a technique in which he can spontaneously convert an electron completely into energy in the laboratory without any other material required. What is the conclusion about this claim from our current understanding of physics?
A) This is possible because Einstein's equation says that mass and energy are equivalent… it is just very difficult to achieve with electrons
B) This is possible and it is done all the time in the high-energy physics labs.
C) The scientist is almost correct… except that in converting the electron to energy, an electron's anti-particle is produced in the process as well.
D) This is not possible because charge conservation would be violated.

12. The most common isotope of Uranium, $^{238}U_{92}$, radioactively decays into lead, $^{206}Pb_{82}$, by a means of a series of alpha and beta particle emissions. How many of each particle must be emitted.
A) 16 alphas, 16 betas B) 16 alphas, 8 betas C) 8 alphas, 6 betas D) 4 alphas, 18 betas

13. Rutherford was the first person to artificially transmute one element into another (nitrogen to oxygen). A nuclear equation for his reaction could be written as follows:

$$\frac{4}{2}He + \frac{14}{7}N \rightarrow \frac{17}{8}O + ?$$

The unknown particle in the above equation is
A) a proton B) a neutron C) an electron D) an alpha particle

14. A nucleus of polonium–218 ($\frac{218}{84}Po$) emits an alpha particle ($\frac{4}{2}\alpha$). The next two elements in radioactive decay chain each emit a beta particle ($\frac{0}{-1}B^-$). What would be the resulting nucleus after these three decays have occurred?

A) $\frac{214}{82}Pb$ B) $\frac{214}{84}Po$ C) $\frac{214}{85}At$ D) $\frac{222}{86}Rn$

15. ${}^{235}_{92}U + {}^1_0n \rightarrow 3\,{}^1_0n + {}^{142}_{56}Ba +$ ________

The additional product of the nuclear fission reaction shown above is

A) ${}^{91}_{36}Kr$ B) ${}^{92}_{35}Br$ C) ${}^{93}_{36}Kr$ D) ${}^{93}_{37}Rb$

16. The nuclide $^{214}Pb_{82}$ emits an electron and becomes nuclide X. Which of the following gives the mass number and atomic number of nuclide X?

	Mass Number	Atomic Number
A)	210	80
B)	213	83
C)	214	81
D)	214	83

17. The nuclear reaction X → Y + Z occurs spontaneously. If M_x, M_Y, and M_Z are the masses of the three particles. which of the following relationships is true"?
A) $M_x < M_y + M_z$ B) $M_x > M_y + M_z$ C) $M_x - M_y < M_z$ D) $M_x - M_z < M_y$

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}H + 4MeV$$

18. The equation above is an illustration of
A) artificially produced radioactive decay
B) naturally occurring radioactive decay
C) nuclear fission
D) nuclear fusion

19. A proton collides with a nucleus of $^{14}_{7}N$. If this collision produces a nucleus of $^{11}_{6}C$ and one other particle, that particle is _____ .
A) a proton B) a neutron C) an alpha particle D) a beta particle

20. A nucleus of tritium contains 2 neutrons and 1 proton. If the nucleus undergoes beta decay, emitting an electron, the nucleus is transmuted into
A) the nucleus of an isotope of helium
B) the nucleus of an isotope of lithium
C) an alpha particle
D) a triton

21. Which of the following statements is true of a beta particle?
A) Its speed in a vacuum is 3 x 10^8 m/s.
B) It is more penetrating than a gamma ray of the same energy.
C) It has a mass of about 1,840 times that of a proton.
D) It can exhibit wave properties.

<u>Questions 22-23</u>
An electron and a positron, each of mass 9.1 x 10^{-31} kilogram, are in the same general vicinity and have very small initial speeds. They then annihilate each other, producing two photons.

22. What is the approximate energy of each emerging photon?
A) 0.51 MeV B) 2.0 MeV C) 4.0 MeV
DE) It cannot be determined unless the frequency of the photon is known.

23. What is the angle between the paths of the emerging photons?
(A) 0° B) 45° C) 90° D) 180°

<u>Questions 24-25</u> Refer to the following reaction:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{138}_{56}Ba + ^{95}_{36}Kr + neutrons + released\ energy$$

24. The total number of free neutrons in the products of this reaction is
A) 2 B) 3 C) 4 D) 5

25. Which of the following statements is always true for neutron-induced fission reactions involving $^{235}_{92}U$?
I. The end products always include Ba and Kr.
II. The rest mass of the end products is less than that of $^{235}_{92}U + ^{1}_{0}n$.
III. The total number of nucleons (protons plus neutrons) in the end products is less than that in $^{235}_{92}U + ^{1}_{0}n$.
A) II only B) III only C) I and II only D) I and III only

26. Force magnitudes between two objects which are inversely proportional to the square of the distance between the objects include which of the following?

I. Gravitational force between two celestial bodies
II. Electrostatic force between two electrons
III. Nuclear force between two neutrons

A) I only B) III only C) I and II only D) II and III only

27. Quantities that are conserved in all nuclear reactions include which of the following?

I. Electric charge
II. Number of nuclei
III. Number of protons

A) I only B) II only C) I and III only D) II and III only

28. A negative beta particle and a gamma ray are emitted during the radioactive decay of a nucleus of $^{214}_{82}Pb$. Which of the following is the resulting nucleus?

A) $^{210}_{80}Hg$ B) $^{214}_{81}Tl$ C) $^{213}_{83}Bi$ D) $^{214}_{83}Bi$

29. When ^{10}B is bombarded by neutrons, a neutron can be absorbed and an alpha particle (^{4}He) emitted. If the ^{10}B target is stationary, the kinetic energy of the reaction products is equal to the.

A) kinetic energy of the incident neutron
B) total energy of the incident neutron
C) energy equivalent of the mass decrease in the reaction
D) energy equivalent of the mass decrease in the reaction plus the kinetic energy of the incident neutron

30. $^{226}_{88}\mathrm{Ra}$ decays into $^{222}_{86}\mathrm{Rn}$ plus

A) a proton B) a neutron C) an electron D) a helium nucleus $\left(^{4}_{2}\mathrm{He}\right)$

31. Correct statements about the binding energy of a nucleus include which of the following?

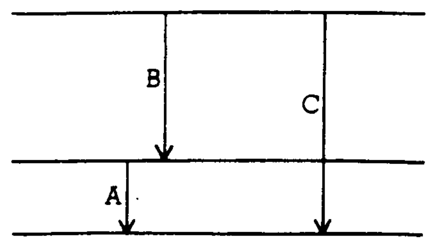
I. It is the energy needed to separate the nucleus into its individual protons and neutrons.
II. It is the energy liberated when the nucleus is formed from the original nucleons.
III. It is the energy equivalent of the apparent loss of mass of its nucleon constituents.

A) I only
B) III only
C) I and II only
D) I, II, and III

AP Physics Free Response Practice – Modern Physics

SECTION A – Quantum Physics and Atom Models

1975B5. The diagram above shows part of an energy-level diagram for a certain atom. The wavelength of the radiation associated with transition A is 600 nm (1 nm = 1 x 10^{-9} m) and that associated with transition B is 300 nm.



a. Determine the energy of a photon associated with transition A.
b. Determine the λ of the radiation associated with transition C
c. Describe qualitatively what will happen to an intense beam of white light (400 to 600 nm) that is sent through this gaseous element

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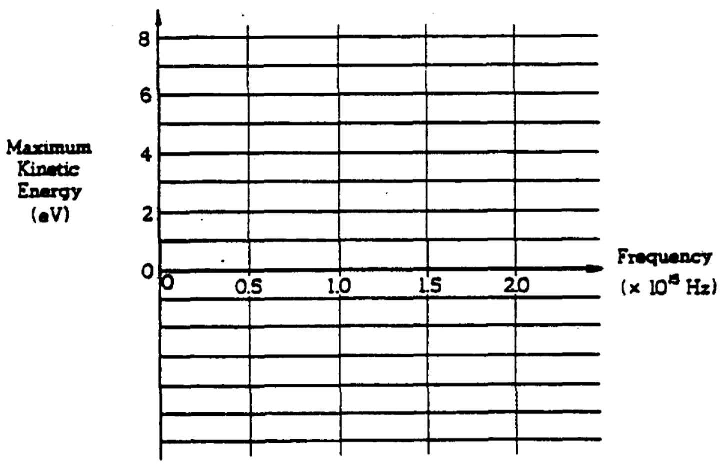
1980B3. In a photoelectric experiment, radiation of several different frequencies was made to shine on a metal surface and the maximum kinetic energy of the ejected electrons was measured at each frequency. Selected results of the experiment are presented in the table:

Frequency (Hz)	Maximum Kinetic Energy of Electrons (eV)
0.5×10^{15}	No electrons ejected
1.0×10^{15}	1.0
1.5×10^{15}	3.0
2.0×10^{15}	5.0

a. On the axes below, plot the data from this photoelectric experiment.



b. Determine the threshold frequency of the metal surface.
c. Determine the work function of the metal surface.
d. When light of frequency 2.0 x 10^{15} hertz strikes the metal surface, electrons of assorted speeds are ejected from the surface. What minimum retarding potential would be required to stop all of the electrons ejected from the surface by light of frequency 2.0 x 10^{15} hertz?
e. Investigation reveals that some electrons ejected from the metal surface move in circular paths. Suggest a reasonable explanation for this electron behavior.

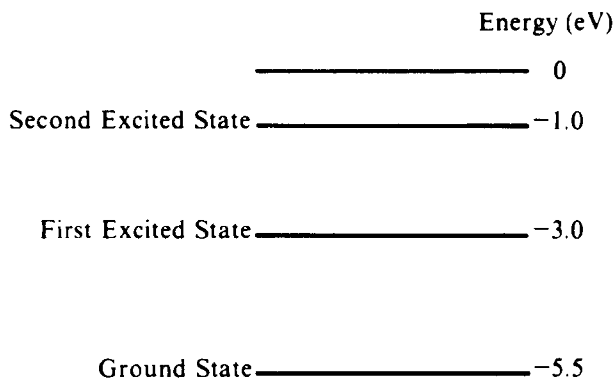
1982B7. Select one of the following experiments:

I. The Michelson-Morley experiment
II. The Rutherford scattering experiment
III. The Compton scattering experiment
IV. The Davisson-Germer experiment

Clearly indicate the experiment you select and write an account of this experiment. Include in your account
a. a labeled diagram of the experimental setup
b. a discussion of the experimental observations
c. the important conclusions of the experiment

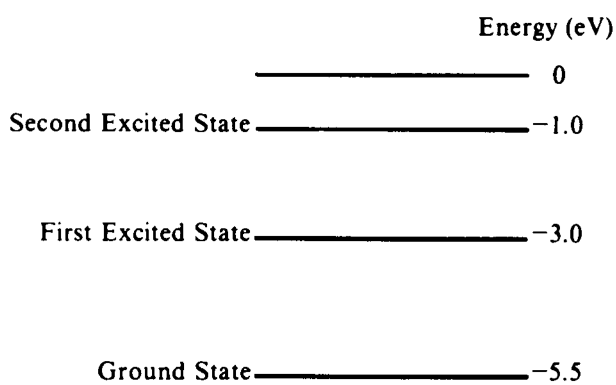
1983B6. An experiment is conducted to investigate the photoelectric effect. When light of frequency 1.0×10^{15} hertz is incident on a photocathode, electrons are emitted. Current due to these electrons can be cut off with a 1.0-volt retarding potential. Light of frequency 1.5×10^{15} hertz produces a photoelectric current that can be cut off with a 3.0-volt retarding potential.

a. Calculate an experimental value of Planck's constant based on these data.
b. Calculate the work function of the photocathode.
c. Will electrons be emitted from the photocathode when green light of wavelength 5.0×10^{-7} meter is incident on the photocathode? Justify your answer.

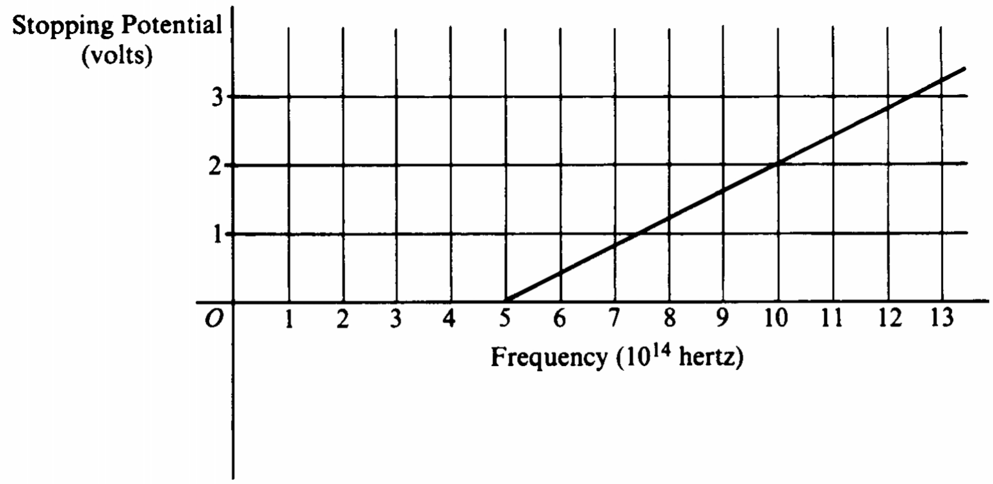


1985B6. An energy-level diagram for a hypothetical atom is shown above.

a. Determine the frequency of the lowest energy photon that could ionize the atom, initially in its ground state.
b. Assume the atom has been excited to the state at -1.0 electron volt.
   i. Determine the wavelength of the photon for each possible spontaneous transition.
   ii. Which, if any, of these wavelengths are in the visible range?
c. Assume the atom is initially in the ground state. Show on the following diagram the possible transitions from the ground state when the atom is irradiated with electromagnetic radiation of wavelengths ranging continuously from 2.5×10^{-7} meter to 10.0×10^{-7} meter.

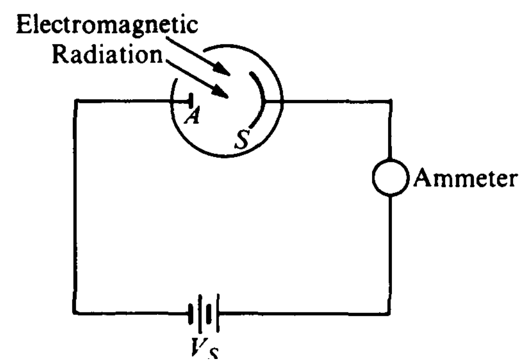


1987B6. In a photoelectric experiment, light is incident on a metal surface. Electrons are ejected from the surface, producing a current in a circuit. A reverse potential is applied in the circuit and adjusted until the current drops to zero. That potential at which the current drops to zero is called the stopping potential. The data obtained for a range of frequencies are graphed below.



a. For a frequency of light that has a stopping potential of 3 volts, what is the maximum kinetic energy of the ejected photoelectrons?
b. From the graph and the value of the electron charge, determine an experimental value for Planck's constant.
c. From the graph, determine the work function for the metal.
d. On the axes above, draw the graph for a different metal surface with a threshold frequency of 6.0 x 10^{14} hertz.

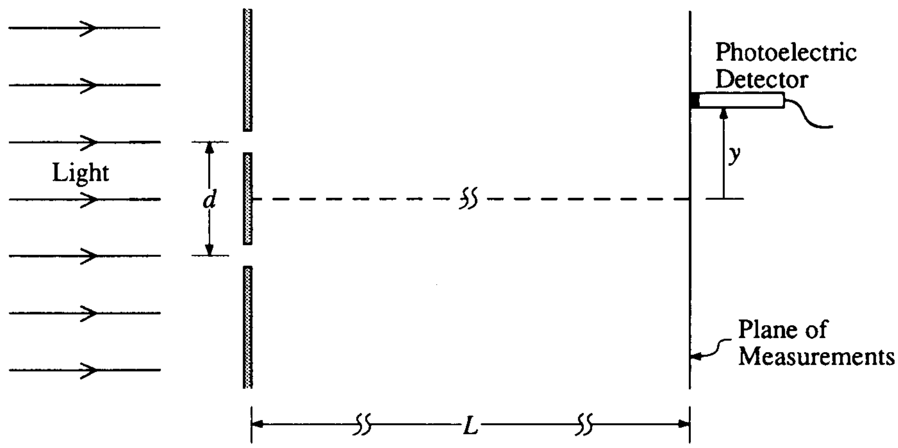
1988B6. Electromagnetic radiation is incident on the surface S of a material as shown. Photoelectrons are emitted from the surface S only for radiation of wavelength 500 nm or less. It is found that for a certain ultraviolet wavelength, which is unknown, a potential V_s of 3 volts is necessary to stop the photoelectrons from reaching the anode A, thus eliminating the photoelectric current.



a. Determine the frequency of the 500 nm radiation.
b. Determine the work function for the material.
c. Determine the energy of the photons associated with the unknown wavelength.
d. Determine the unknown wavelength.

1990B5. In a television picture tube, electrons are accelerated from rest through a potential difference of 12,000 volts and move toward the screen of the tube. When the electrons strike the screen, x-ray photons are emitted. Determine:
a. the speed of an electron just before it strikes the screen
b. the number of electrons arriving at the screen per second if the flow of electrons in the tube is 0.01 coulomb per second

An x-ray of maximum energy is produced when an electron striking the screen gives up all of its kinetic energy. For such x-rays, determine:
c. the frequency
d. the wavelength
e. the photon momentum



1991B6. Light consisting of two wavelengths, $\lambda_a = 4.4 \times 10^{-7}$ meter and $\lambda_b = 5.5 \times 10^{-7}$ meter, is incident normally on a barrier with two slits separated by a distance d. The intensity distribution is measured along a plane that is a distance L = 0.85 meter from the slits as shown above. The movable detector contains a photoelectric cell whose position y is measured from the central maximum. The first-order maximum for the longer wavelength λ_b occurs at $y = 1.2 \times 10^{-2}$ meter.

a. Determine the slit separation d.

b. At what position Y_a does the first-order maximum occur for the shorter wavelength λ_a?

In a different experiment, light containing many wavelengths is incident on the slits. It is found that the photosensitive surface in the detector is insensitive to light with wavelengths longer than 6.0×10^{-7} m.

c. Determine the work function of the photosensitive surface.

d. Determine the maximum kinetic energy of electrons ejected from the photosensitive surface when exposed. to light of wavelength $\lambda = 4.4 \times 10^{-7}$ m.

1992B4. The ground-state energy of a hypothetical atom is at –10.0 eV. When these atoms, in the ground state, are illuminated with light, only the wavelengths of 207 nanometers and 146 nanometers are absorbed by the atoms. (1 nanometer = 10^{-9} meter).

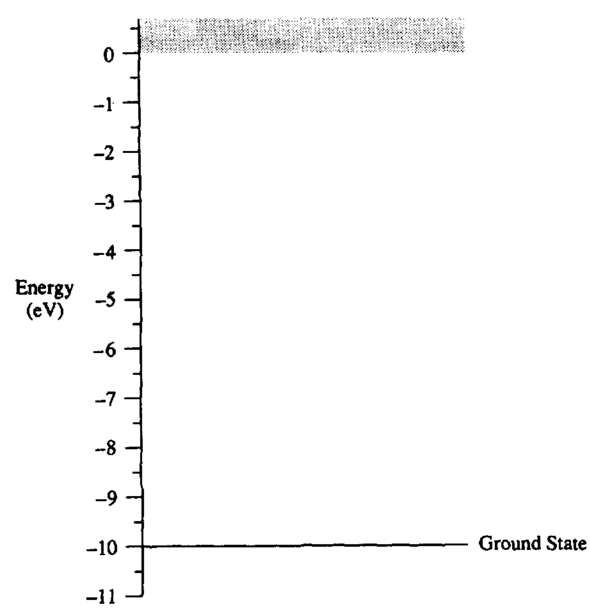
a. Calculate the energies of the photons of light of the two absorption-spectrum wavelengths.

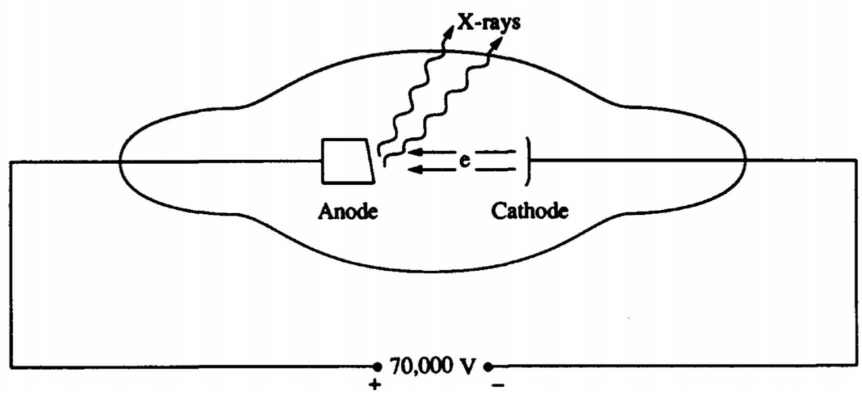
b. Complete the energy-level diagram shown for these atoms by showing all the excited energy states.

c. Show by arrows on the energy-level diagram all of the possible transitions that would produce emission spectrum lines.

d. What would be the wavelength of the emission line corresponding to the transition from the second excited state to the first excited state?

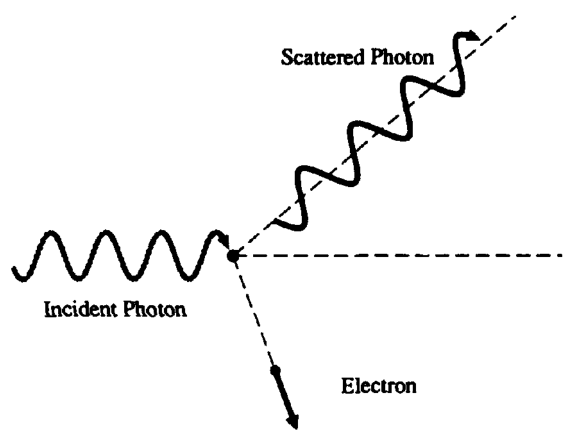
e. Would the emission line in (d) be visible? Briefly justify your answer





1993B6. In the x-ray tube shown above, a potential difference of 70,000 volts is applied across the two electrodes. Electrons emitted from the cathode are accelerated to the anode, where x-rays are produced.

a. Determine the maximum frequency of the x-rays produced by the tube.
b. Determine the maximum momentum of the x-ray photons produced by the tube.



An x-ray photon of the maximum energy produced by this tube leaves the tube and collides elastically with an electron at rest. As a result, the electron recoils and the x-ray is scattered, as shown above. The frequency of the scattered x-ray photon is 1.64×10^{19} hertz.

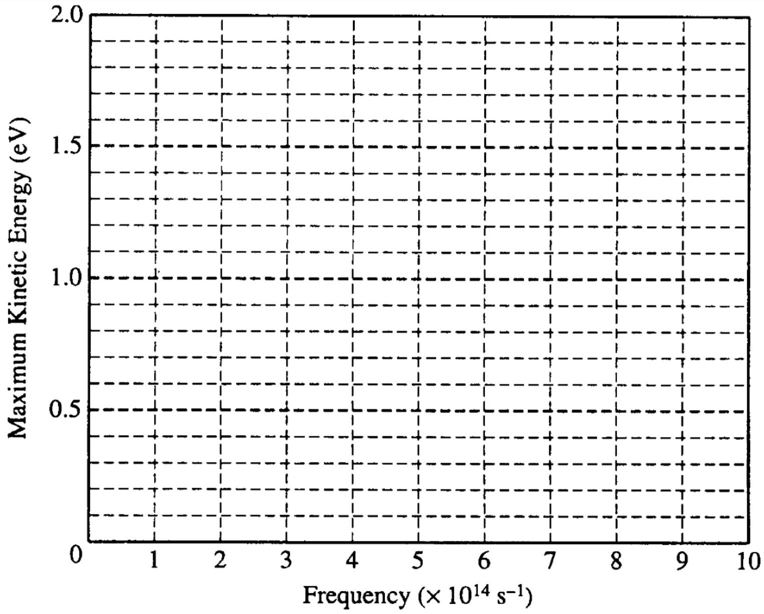
c. Determine the kinetic energy of the recoiled electron.
d. Determine the magnitude of the momentum of the recoiled electron.
e. Determine the deBroglie wavelength of the electron

1994B3

A series of measurements were taken of the maximum kinetic energy of photoelectrons emitted from a metallic surface when light of various frequencies is incident on the surface.

a. The table below lists the measurements that were taken. On the axes below, plot the kinetic energy versus light frequency for the five data points given. Draw on the graph the line that is your estimate of the best straight-line fit to the data points

Light Frequency (10^{14} s^{-1})	Maximum Kinetic Energy (electron volts)
5.00	0.10
6.00	0.45
7.00	0.95
8.00	1.30
9.00	1.45



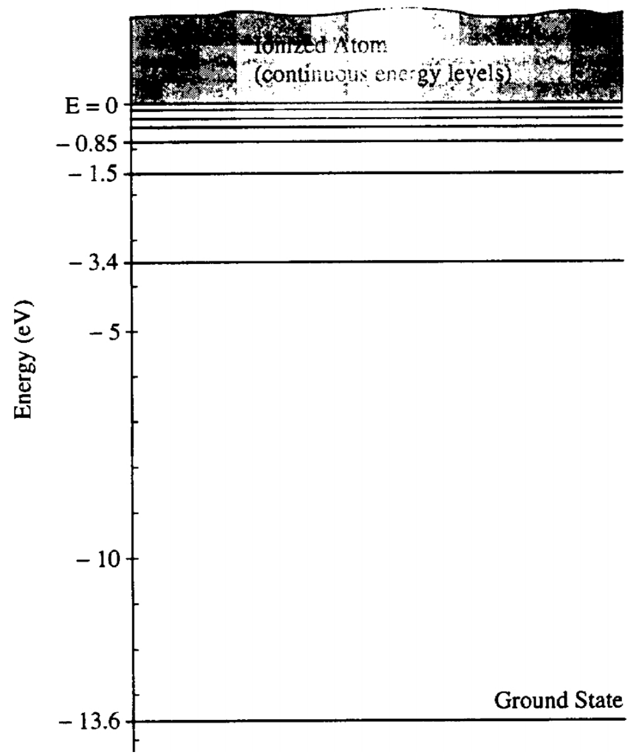
b. From this experiment, determine a value of Planck's constant h in units of electron volt-seconds. Briefly explain how you did this

1995B4. A free electron with negligible kinetic energy is captured by a stationary proton to form an excited state of the hydrogen atom. During this process a photon of energy E_a is emitted, followed shortly by another photon of energy 10.2 electron volts. No further photons are emitted. The ionization energy of hydrogen is 13.6 electron volts.

a. Determine the wavelength of the 10.2 eV photon.

b. Determine the following for the first photon emitted.
   i. The energy E_a of the photon
   ii. The frequency that corresponds to this energy

c. The following diagram shows some of the energy levels of the hydrogen atom, including those that are involved in the processes described above. Draw arrows on the diagram showing only the transitions involved in these processes.



d. The atom is in its ground state when a 15 eV photon interacts with it. All the photon's energy is transferred to the electron, freeing it from the atom. Determine the following.
   i. The kinetic energy of the ejected electron
   ii. The de Broglie wavelength of the electron

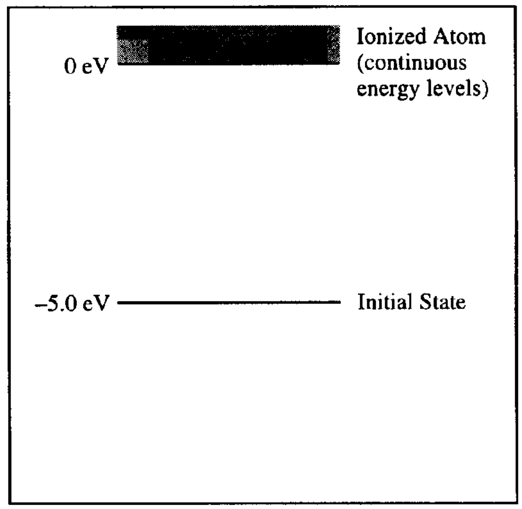
1997B6
Select one of the experiments below, and for the experiment you pick answer parts (a) and (b) that follow.

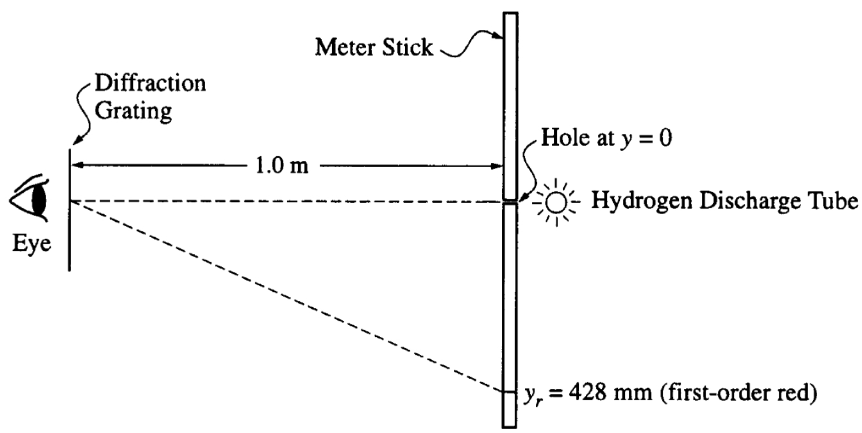
i. Rutherford scattering experiment ii. Michelson-Morley experiment iii. Photoelectric-effect experiment

a. Draw a simple diagram representing the experimental setup and label the important components.
b. Briefly state the key observation(s) in this experiment and indicate what can be concluded from them.

A monatomic gas is illuminated with visible light of wavelength 400 nm. The gas is observed to absorb some of the light and subsequently to emit visible light at both 400 nm and 600 nm.

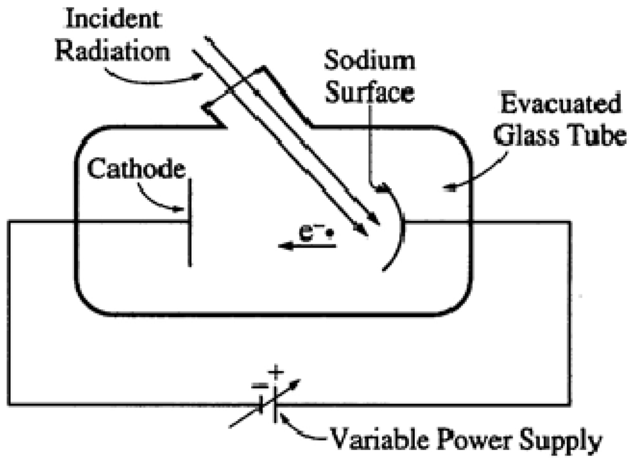
c. In the box, complete an energy level diagram that would be consistent with these observations. Indicate and label the observed absorption and emissions.
d. If the initial state of the atoms has energy –5.0 eV, what is the energy of the state to which the atoms were excited by the 400 nm light?
e. At which other wavelength(s) outside the visible range do these atoms emit radiation after they are excited by the 400 nm light?





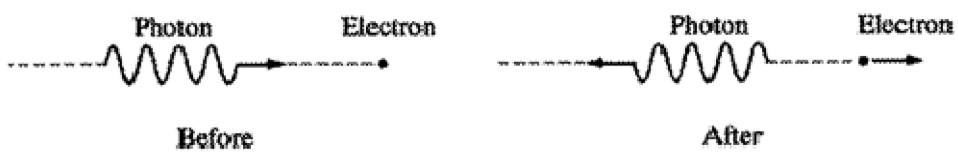
1998B7. A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance y_r = 428 mm from the hole.

a. Calculate the wavelength of the red line in the hydrogen spectrum.
b. According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6\ \text{eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with n = 2. Use the Bohr model to determine the value of n for the initial level of the transition.
c. Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.



2000B5. A sodium photoelectric surface with work function 2.3 eV is illuminated by electromagnetic radiation and emits electrons. The electrons travel toward a negatively charged cathode and complete the circuit shown above. The potential difference supplied by the power supply is increased, and when it reaches 4.5 V, no electrons reach the cathode.

a. For the electrons emitted from the sodium surface, calculate the following.
   i. The maximum kinetic energy
   ii. The speed at this maximum kinetic energy
b. Calculate the wavelength of the radiation that is incident on the sodium surface.
c. Calculate the minimum frequency of light that will cause photoemission from this sodium surface.



2002B7. A photon of wavelength 2.0 x 10^{-11} m strikes a free electron of mass m_e that is initially at rest, as shown above left. After the collision, the photon is shifted in wavelength by an amount $\Delta\lambda = 2h/m_ec$, and reversed in direction, as shown above right.

(a) Determine the energy in joules of the incident photon.
(b) Determine the magnitude of the momentum of the incident photon.
(c) Indicate below whether the photon wavelength is increased or decreased by the interaction.
   ____Increased   ________Decreased
   Explain your reasoning.
(d) Determine the magnitude of the momentum acquired by the electron.

B2002B7. An experimenter determines that when a beam of mono–energetic electrons bombards a sample of a pure gas, atoms of the gas are excited if the kinetic energy of each electron in the beam is 3.70 eV or greater.

(a) Determine the deBroglie wavelength of 3.70 eV electrons.

(b) Once the gas is excited by 3.70 eV electrons, it emits monochromatic light. Determine the wavelength of this light.

Experiments reveal that two additional wavelengths are emitted if the beam energy is raised to at least 4.90 eV.

(c) Construct an energy-level diagram consistent with this information and determine the energies of the photons associated with those two additional wavelengths.

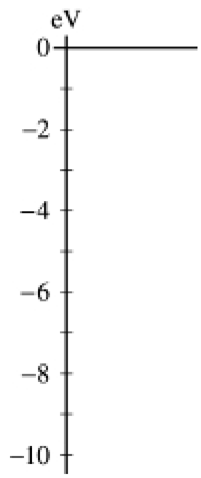
B2003B7. An experiment is performed on a sample of atoms known to have a ground state of –5.0 eV. The gas is illuminated with "white light" (400 – 700 nm). A spectrometer capable of analyzing radiation in this range is used to measure the radiation. The sample is observed to absorb light at only 400 nm. After the "white light" is turned off, the sample is observed to emit visible radiation of 400 nm and 600 nm.

(a) In the space below, determine the values of the energy levels and on the following scale sketch an energy level diagram showing the energy values in eV's and the relative positions of:

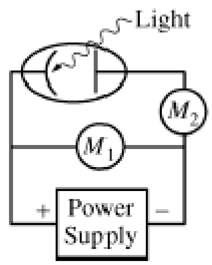
i. the ground state

ii. the energy level to which the system was first excited

iii. one other energy level that the experiment suggests may exist



(b) What is the wavelength of any other radiation, if any, that might have been emitted in the experiment? Why was it not observed?



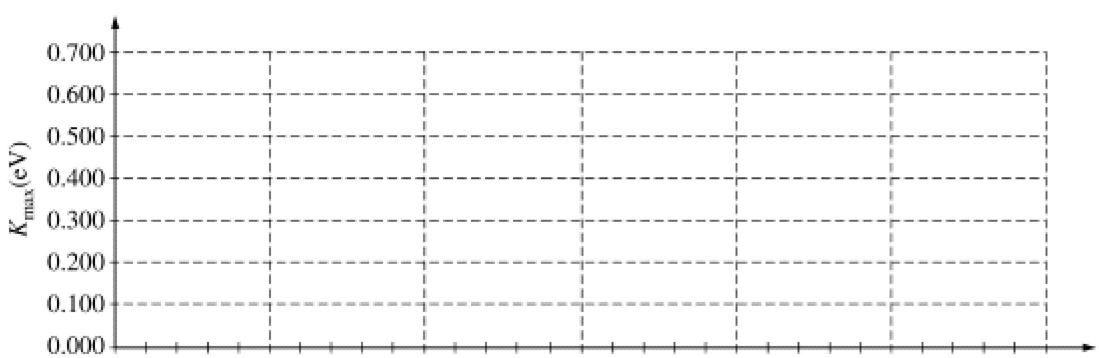
2004B6. A student performs a photoelectric effect experiment in which light of various frequencies is incident on a photosensitive metal plate. This plate, a second metal plate, and a power supply are connected in a circuit, which also contains two meters, M_1 and M_2, as shown above.
The student shines light of a specific wavelength λ onto the plate. The voltage on the power supply is then adjusted until there is no more current in the circuit, and this voltage is recorded as the stopping potential V_s .
The student then repeats the experiment several more times with different wavelengths of light. The data, along with other values calculated from it, are recorded in the table below.

λ (m)	4.00×10^{-7}	4.25×10^{-7}	4.50×10^{-7}	4.75×10^{-7}
V_S (volts)	0.65	0.45	0.30	0.15
f (Hz)	7.50×10^{14}	7.06×10^{14}	6.67×10^{14}	6.32×10^{14}
K_{max} (eV)	0.65	0.45	0.30	0.15

(a) Indicate which meter is used as an ammeter and which meter is used as a voltmeter by checking the appropriate spaces below.

	M_1	M_2
Ammeter	_____	_____
Voltmeter	_____	_____

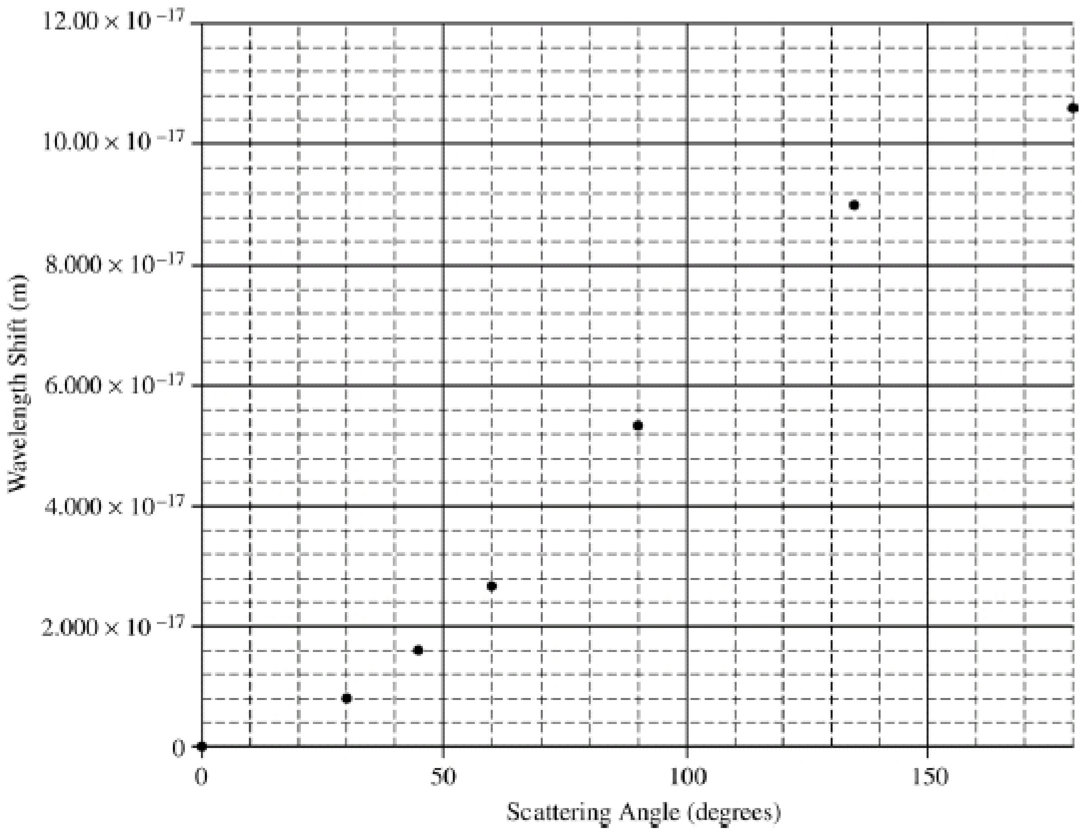
(b) Use the data above to plot a graph of *Kmax* versus *f* on the axes below, and sketch a best-fit line through the data.



(c) Use the best-fit line you sketched in part (b) to calculate an experimental value for Planck's constant.

(d) If the student had used a different metal with a larger work function, how would the graph you sketched in part (b) be different? Explain your reasoning.

B2004B6.
An incident gamma ray photon of wavelength 1.400×10^{-14} m is scattered off a stationary nucleus. The shift in wavelength of the photon is measured for various scattering angles, and the results are plotted on the graph shown below.



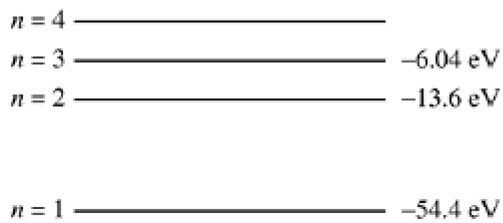
(a) On the graph, sketch a best-fit curve to the data.
In one of the trials, the photon is scattered at an angle of 120° with its original direction.

(b) Calculate the wavelength of this photon after it is scattered off the nucleus.

(c) Calculate the momentum of this scattered photon.

(d) Calculate the energy that this scattering event imparts to the recoiling nucleus.

2005B7



The diagram above shows the lowest four discrete energy levels of an atom. An electron in the $n = 4$ state makes a transition to the $n = 2$ state, emitting a photon of wavelength 121.9 nm.
(a) Calculate the energy level of the $n = 4$ state.
(b) Calculate the momentum of the photon.

The photon is then incident on a silver surface in a photoelectric experiment, and the surface emits an electron with maximum possible kinetic energy. The work function of silver is 4.7 eV.
(c) Calculate the kinetic energy, in eV, of the emitted electron.
(d) Determine the stopping potential for the emitted electron.

B2005B7. A monochromatic source emits a 2.5 mW beam of light of wavelength 450 nm.

(a) Calculate the energy of a photon in the beam.
(b) Calculate the number of photons emitted by the source in 5 minutes.

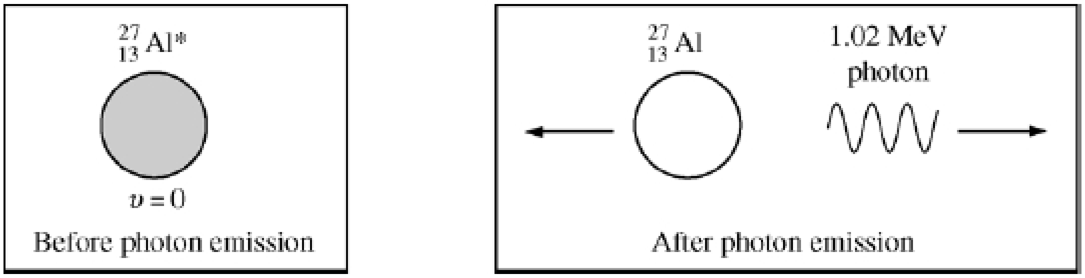
The beam is incident on the surface of a metal in a photoelectric-effect experiment. The stopping potential for the emitted electron is measured to be 0.86 V.

(c) Calculate the maximum speed of the emitted electrons.
(d) Calculate the de Broglie wavelength of the most energetic electrons.

2006B6. A photon with a wavelength of 1.5×10^{-8} m is emitted from an ultraviolet source into a vacuum.
(a) Calculate the energy of the photon.
(b) Calculate the de Broglie wavelength of an electron with kinetic energy equal to the energy of the photon.
(c) Describe an experiment that illustrates the wave properties of this electron.

2008B7. In an electron microscope, a tungsten cathode with work function 4.5 eV is heated to release electrons that are then initially at rest just outside the cathode. The electrons are accelerated by a potential difference to create a beam of electrons with a de Broglie wavelength of 0.038 nm.
(a) Calculate the momentum of an electron in the beam, in kg-m/s.
(b) Calculate the kinetic energy of an electron in the beam, in joules.
(c) Calculate the accelerating voltage.
(d) Suppose that light, instead of heat, is used to release the electrons from the cathode. What minimum frequency of light is needed to accomplish this?

B2008B7.

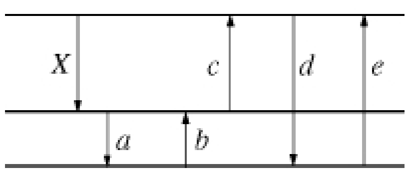


Following a nuclear reaction, a nucleus of aluminum is at rest in an excited state represented by $^{27}_{13}Al^*$, as shown above left. The excited nucleus returns to the ground state $^{27}_{13}Al$ by emitting a gamma ray photon of energy 1.02 MeV, as shown above right. The aluminum nucleus in the ground state has a mass of 4.48×10^{-26} kg.

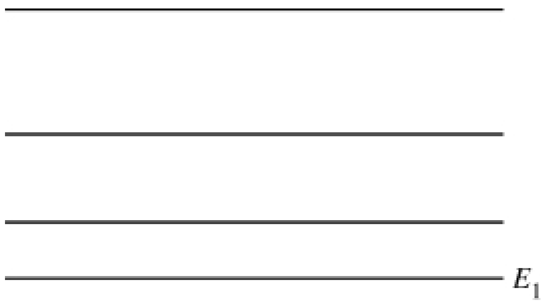
(a) Calculate the wavelength of the emitted photon in meters.
(b) Calculate the momentum of the emitted photon in kg-m/s.
(c) Calculate the speed of the recoiling nucleus in m/s.
(d) Calculate the kinetic energy of the recoiling nucleus in joules.

2009B7. A photon of wavelength 250 nm ejects an electron from a metal. The ejected electron has a de Broglie wavelength of 0.85 nm.

(a) Calculate the kinetic energy of the electron.
(b) Assuming that the kinetic energy found in (a) is the maximum kinetic energy that it could have, calculate the work function of the metal.
(c) The incident photon was created when an atom underwent an electronic transition. On the energy level diagram of the atom below, the transition labeled *X* corresponds to a photon wavelength of 400 nm. Indicate which transition could be the source of the original 250 nm photon by circling the correct letter. Justify your answer.



B2009B6.



The electron energy levels above are for an electron confined to a certain very small one-dimensional region of space. The energy E_n of the levels, where $n = 1, 2, 3, \ldots$, is given by $E_n = n^2 E_1$. Express all algebraic answers in terms of E_1 and fundamental constants.

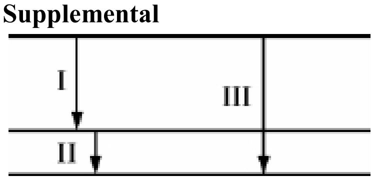
(a) On the diagram above, label the three excited energy levels with the values for their energies in terms of E_1, the energy of the ground state.

(b) Calculate the smallest frequency of light that can be absorbed by an electron in this system when it is in the ground state, $n = 1$.

(c) If an electron is raised into the second excited state, draw on the diagram all the possible transitions that the electron can make in returning to the ground state.

(d) Calculate the wavelength of the highest energy photon that can be emitted in the transitions in part (c).

Supplemental



The diagram above shows a portion of the energy-level diagram for a particular atom. When the atom undergoes transition I, the wavelength of the emitted radiation is 400 nm, and when it undergoes transition II, the wavelength is 700 nm.

(a) Calculate the wavelength of the emitted radiation when the atom undergoes transition III.

A photon emitted during transition III is then incident on a metal surface of work function 2.1 eV.

(b) Calculate the maximum kinetic energy of the electron ejected from the metal by the photon.

(c) Calculate the de Broglie wavelength of the ejected electron.

SECTION B – Nuclear Physics

1989B6. A lithium nucleus, while at rest, decays into a helium nucleus of rest mass 6.6483 x 10^{-27} kilogram and a proton of rest mass 1.6726 x 10^{-27} kilogram, as shown by the following reaction.

$$^{5}_{3}Li \rightarrow ^{4}_{2}He + ^{1}_{1}H$$

In this reaction, momentum and total energy are conserved. After the decay, the proton moves with a speed of 1.95 x 10^{7} m/s.

a. Determine the kinetic energy of the proton.
b. Determine the speed of the helium nucleus.
c. Determine the kinetic energy of the helium nucleus.
d. Determine the mass that is transformed into kinetic energy in this decay.
e. Determine the rest mass of the lithium nucleus.

1996B5. An unstable nucleus that is initially at rest decays into a nucleus of fermium-252 containing 100 protons and 152 neutrons and an alpha particle that has a kinetic energy of 8.42 MeV. The atomic masses of helium-4 and fermium-252 are 4.00260 u and 252.08249 u, respectively.

a. What is the atomic number of the original unstable nucleus?
b. What is the velocity of the alpha particle?
c. Where does the kinetic energy of the alpha particle come from? Explain briefly.
d. Assuming all of the energy released in the reaction is in the form of kinetic energy of the alpha particle, determine the exact mass of the original unstable nucleus, to an accuracy of 3 thousandths of a decimal.
e. Suppose that the fermium-252 nucleus could undergo a decay in which a β^- particle was produced. How would this affect the atomic number of the nucleus? Explain briefly.

1999B4. A Geiger counter is used to measure the decay of a radioactive sample of bismuth 212 over a period of time.

a. The bismuth isotope decays into thallium by emitting an alpha particle according to the following equation:

$$^{212}_{83}Bi \rightarrow Tl + \alpha$$

Determine the atomic number Z and the mass number A of the thallium nuclei produced and enter your answers in the spaces provided below.

Z= ____________________ A= ____________________

b. The mass of the alpha particle is 6.64 x 10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.
i. Determine the momentum of the alpha particle.
ii. Determine the kinetic energy of the recoiling thallium nucleus.
c. Determine the total energy released during the decay of 1 mole of bismuth 212.

2001B7. Consider the following nuclear fusion reaction that uses deuterium as fuel. $3(^{2}_{1}\mathrm{H}) \rightarrow ^{4}_{2}\mathrm{He} + ^{1}_{1}\mathrm{H} + ^{1}_{0}\mathrm{n}$

a. Determine the mass defect of a single reaction, given the following information.

$$^{2}_{1}H = 2.0141u \qquad ^{4}_{2}He = 4.0026u \qquad ^{1}_{1}H = 1.0078u \qquad ^{1}_{0}n = 1.0087u$$

b. Determine the energy in joules released during a single fusion reaction.
c. The United States requires about 10^{20} J per year to meet its energy needs. How many deuterium atoms would be necessary to provide this magnitude of energy?
d. What mass of deuterium, in kg, is needed to provide this energy per year

B2006B6. An electron of mass m is initially moving with a constant speed v , where $v << c$. Express all algebraic answers in terms of the given quantities and fundamental constants.
(a) Determine the kinetic energy of the electron.
(b) Determine the de Broglie wavelength of the electron.

The electron encounters a particle with the same mass and opposite charge (a positron) moving with the same speed in the opposite direction. The two particles undergo a head-on collision, which results in the disappearance of both particles and the production of two photons of the same energy.
(c) Determine the energy of each photon.
(d) Determine the wavelength of each photon.
(e) Explain why there must be two photons produced instead of just one.

B2007B7. In the vicinity of a heavy nucleus, a high-energy photon can be converted into two particles: an electron and a positron. A positron has the same mass as the electron and equal but opposite charge. This process is called pair production.
(a) Calculate the rest energy of an electron, in eV.
(b) Determine the minimum energy, in eV, that a photon must have to give rise to pair production.
(c) Calculate the wavelength corresponding to the photon energy found in part (b).
(d) Calculate the momentum of the photon.

2007B7. It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron–positron pair before annihilation is negligible compared to the energy of the photons created.
(a) Calculate, in eV, the rest energy of a positron.
(b) Determine, in eV, the energy each emitted photon must have.
(c) Calculate the wavelength of each created photon.
(d) Calculate the magnitude of the momentum of each photon.
(e) Determine the total momentum of the two-photon system.

AP Physics Multiple Choice Practice – Modern Physics – ANSWERS

SECTION A – Quantum Physics and Atom Models

	Solution	Answer
1.	The de Broglie wavelength is given by $p = h / \lambda$. Since $p = mv$, $\lambda = h / mv$. Therefore, $\lambda_{new} = h/[(3m)(2v)] = \lambda/6$.	D
2.	From $K = hf - \phi$ … $y = mx + b$ … the work function is the y intercept, extend the line.	A
3.	4–3,3–2,2–1 … or 4–2, 2–1 … or 4–3, 3–1 … or 4–1 … this is a total of 6 different transitions.	D
4.	Stopping potential is given by. $K=V_{stop}q$ ... combined with $K = hf - \phi$, we see the stopping potential is related to the incoming light energy minus the work function. However, none of the choices give a proper result. The answer depends on what that actual incoming energy hf and work function are. Here is an example. Lets say hf was 3eV and the ϕ was 2 eV initially. From $Vq=hf- \phi$ … the stopping potential for an electron (1e) would be equal to 1eV. Now if we were to half the work function, the new stopping potential would be 3eV – 1eV = 2 eV so it appears that the stopping potential doubled. But that result only works for those sample numbers. Lets assume instead that hf = 10eV and ϕ = 2eV. Now initially the V_{stop} = 8eV. Then we again half the work function … 10eV – 1 eV and we get a stopping potential of 9V .. not nearly doubled this time. The results depend on the actual numbers used because of the minus sign in the equation and not a simple multiplier effect.	D
5.	To transition to the $-12eV$ state with only two photon emissions, the only options are for the electron to make the following transitions: $-1eV \rightarrow -3eV \rightarrow -12eV$ giving us photons of energy $2eV$ and $9eV$ or $-1eV \rightarrow -7\ eV \rightarrow -12eV$ giving photons of energy $6eV$ and $5eV$. This means that the 4 eV photon is not possible with only two transitions.	B
6.	$K = hf - \phi$ … now double hf … $K_{new} = 2hf - \phi$ … (now sub in the first equation rearranged for hf, into the second equation) … $K_{new} = 2(K+ \phi) - \phi = 2K + 2\phi - \phi$ … $K_{new} = 2K + \phi$ So the new energy is increased by double the old energy + the work function value.	D
7.	From above $\lambda = h / mv$ … Since $K = ½ mv^2$, 2x K means $\sqrt{2}$x v. So when we plug in the new velocity of $\sqrt{2}v$, the wavelength decreases by this factor since we divide.	A
8.	3 to 1 would be a higher energy emission. More energy means more frequency, and less λ but these are not choices. From $p = h / \lambda$, less λ means more momentum.	D
9.	Below a threshold frequency, there would be no emissions and thus zero K for everything below that point. Above that threshold, more frequency means more K based on $K = hf - \phi$, with h as the constant slope. Graph A has all these properties.	A
10.	The following formulas apply. $K = Vq$ … $K = ½ mv^2$ … $p = mv$ … $p=h/ \lambda$ To get half the λ, the p must be doubled … To double the momentum, the velocity must be doubled … When the velocity is doubled, the Kinetic energy is 4x as much … To get 4x the K, we need 4x the potential.	D
11.	The ground state is at –14eV. The next excited state is 4eV higher (at –10eV) which cant be reached since we are only putting in a range of 7–10. So we try the next jump to the – 5eV state. This would require and input of 9 eV and this is possible since it falls in the range. The next state –3eV is not possible since it would require 11 eV input. So the only excited state we can be brought to with this energy input is the – 5eV state. From this state we will now go through	B

emissions as the electrons fall back down to the ground state. This can be done through three possible jumps:
–5eV→–10eV, then –10eV→–14eV or it could go directly from –5eV→–14eV.
In these three scenarios, the emissions possible are 5, 4 and 9.

12. Big λ means the least energy based on $E=hc/\lambda$. The least energy corresponds to the smallest energy level jump which is 4–3. D

13. The quantization of energy levels is from de Broglie and the relationship of momentum to wavelength through matter–waves. de Broglie theorized that electrons have wavelike properties and must exist in whole number multiples of wavelengths around an orbit to so they interfere constructively and do not get knocked out. A

14. From $p=h/\lambda$, and $c=f\lambda$ … $p = hf/c$. There is a direct relationship between p and f. A

15. The K of each photoelectron is given by. $K = hf - \phi$. To reduce the energy of each photon, we need less f (which means more λ) for the incoming light. Since intensity is directly related to the number of photoelectrons emitted we want to increase the intensity. A,C

16. The photoelectric current is directly related to the number of photoelectrons emitted; the more photoelectrons the more the current. Also, the # of photoelectrons is directly related to the intensity. This means that photoelectric current and intensity also have a direct relationship. When we are above the threshold frequency, 0 intensity would correspond to 0 current, but as intensity increases, the current increases proportionally. D

17. We find the total energy produced in 1 second and then use the energy of 1 photon to determine how many photons would be emitted. B
Total energy = $W = Pt = 50000$ (1 sec) = 50000 J = $5\text{x}10^{4}$
Energy of 1 photon $E = hc / \lambda = 2\text{x}10^{-25} / 4 = 0.5\text{x}10^{-25} = 5\text{x}10^{-26}$
Total Energy / Energy of 1 photon = # photons released.
$5\text{x}10^{4} / 5\text{x}10^{-26} = 10^{30}$

18. Energy of a photon is related to frequency. The red light has a lower frequency and thus less energy per photon. Intensity is the total energy of the beam. To have the same intensity, there would need to be more of the lower energy red photons. D

19. The energy of the electrons is the kinetic energy given by $W = Vq = K$. Doubling the voltage doubles the energy of the electrons. The emitted x–ray energy coming from the electron energy is given by $E=hf$ and with double the energy there should be double the frequency. D

SECTION B – Nuclear Physics

	Solution	Answer
1.	For a positron to be emitted, the oxygen must have undergone beta+ decay, which is the opposite of beta$^-$ decay. In beta+ decay a proton turns into a neutron + the emitted beta particle. The mass number stays the same (P+N still the same), but the atomic number goes down by 1 since there is 1 less proton.	A
2.	An alpha particle is $^4He_2$ so reduce the atomic mass by 4 and the atomic number by 2.	A
3.	In beta$^-$ decay, a neutron turns into a proton. Atomic mass same, mass number +1.	D
4.	Equate E=hf to E=mc^2 … m = hf/c^2.	A
5.	For everything to add up properly, we need … $\frac{1}{0}$ which is a neutron.	C
6.	Same as above.	C
7.	Uranium split by a neutron is called fission.	A
8.	Merging together two elements (He usually being one of them) is called fusion.	B
9.	The mass number has changed by 28, the atomic number has changed by 10. 7 alpha particles ($^4He_2$)*7 equates to a loss of 28 for atomic mass and 14 for atomic number. If only the alpha particles were emitted, 4 protons would be missing. Those protons must have come from the conversion of neutrons into protons which would happen with the release of 4 beta particles.	A
10.	To balance the nuclear reaction, the sum of the values across the "top" and across the "bottom" must match… That is, we have $4 + 9 = 12 + A \rightarrow A = 1$ and $2 + 4 = 6 + Z \rightarrow Z = 0$. This gives us a particle with 1 nucleon, but 0 protons. This is a neutron.	D
11.	Conservation of charge is required. Eliminating an electron by itself violates this. *However, when and electron (–) meets a positron (+) the matter and antimatter can annihilate to produce energy and the + and – charges can neutralize to conserve charge .. just as a side note.*	D
12.	This is the similar to problem 12. Beta particles do not change the atomic mass number since there is simply a conversion between nucleons, so the only way to reduce the mass number is by emitting alpha particles. The mass number goes down by 32 and each alpha particle reduces it by 4 so 8 alpha particles are needed. 8 alpha particles by themselves would also reduce the atomic # by 16, but it only ends up reduced by 10 so there are 6 protons needed. These 6 protons come from the beta decay where 6 neutrons turn into protons and release 6 beta particles.	C
13.	For everything to add up properly, we need … $\frac{1}{1}$ which is a proton.	A
14.	First in the alpha decay, the atomic mass goes down by 4 and the atomic number goes down by 2 leaving $^{214}X_{82}$ … then in the two beta decays, a neutron turns into a proton each time increasing the atomic number by two leaving … $^{214}X_{84}$.	B
15.	Simply make sure everything adds up to get the missing piece.	A
16.	$^{214}Pb_{82} \rightarrow X + {}^0e_{-1}$ … For everything to add up, we need $^{214}X_{83}$	D

17. In a nuclear reaction, the total mass before must be larger than the total mass after since some of the mass will be 'missing' afterwards (mass defect) in the form of released energy. B

18. In this reaction, two light elements are fusing together and producing a heavier element. This is fusion. D

19. The reaction is as follows ${}^{1}p_1 + {}^{14}N_7 \rightarrow {}^{11}C_6 + X$ … to make it all add up X must be an alpha. C

20. We start with 2 neutrons and 1 proton. In beta decay with the emission of an electron, the process involves a neutron turning into a proton. The resulting nucleus would have 1 neutron and 2 protons. An atomic number of 2 is defined as He. It is ${}^{3}He_2$ which is an isotope of ${}^{4}He_2$. A

21. A beta particle, like all matter, can exhibit wave properties. Since the particle is so small, it can more readily show these wave properties than normal size matter. D

22. Using $E=mc^2$ with twice the mass since two particles are destroyed $= (2*9.1\text{x}10^{-31})(3\text{x}10^{8})^2 = 1.64\text{x}10^{-13}$ J … $2.63\text{x}10^{-13}$ J * (1 eV / $1.6\text{x}10^{-19}$ J) = $1.02\text{x}10^{6}$ eV. This is the total energy released, and since there are two photons we split it in half. A

23. To conserve momentum, the photons must move in opposite directions. D

24. For everything to add up properly, 3 neutrons are needed. B

25. I. is Not True, for the following reason: A
In fission, and U–235 nucleus is broken into fragments that make smaller elements + neutrons + energy. The fragments created are not always the same and there is a statistical probability of which fragments can be created. The reaction provided in this problem is the most probable but other elements can be formed such as the following U–235 fission reaction:
U-235 + n → Zr-94 + Te-139 + 3n + energy. There are actually many combinations of fragments that can be released. Small amounts of mass are missing as released energy but adding the whole numbers of the reaction will always balance the equation for a given reaction.
II. is TRUE. As explained above, as small amount of the mass will be missing in the form of energy after the reaction completes. This is necessary to produce the energy from the reaction.
III. is Not True. Again as explained in the first paragraph. There will be a small amount of mass missing but adding the whole numbers before and after will always result in the same numbers of particles for a fission reaction.

26. $F_g=Gmm/r^2$ … $F_e = kqq/r^2$ … The electric and gravitational forces are inverse squared as shown from the equations here. Nuclear is not. This is fact and we don't know why. It was one of Einstein's last puzzles and he considered it a great failure of his to not solve this. It is called grand unification theory that attempts to combine all of the four fundamental forces into one unified force. It is a hot topic in modern physics that is as of yet unsolved. C

27. Some reactions conserve all of these, others do not. Clearly the numbers of protons is not conserved as evidenced by beta decay. The "number" of nuclei is more often conserved but in some reactions such as annihilation the nuclei are disintegrated and converted into energy. This agrees with the law of conservation of matter and energy, but when looking at the total numbers of particles before and the total numbers of particles after, you would say that number is not conserved. Charge is a fundamental conservation law and it always conserved. Even in the annihilation example, the net charge before was zero and is zero after. A

28. ${}^{214}Pb_{82} \rightarrow {}^{0}B_{-1} + \gamma + ?$ … For everything to add up, the missing product is ${}^{214}X_{83}$ D

29. This is a mass defect question. The energy released in the reaction is equal the equivalence of the missing mass comparing the products and reactants. D

30. For everything to add up we need a helium nucleus (alpha particle). D

31. These are all true statements about binding energy. D

SECTION A – Quantum Physics and Atom Models

1975B5.

a) $E_a = hc / \lambda_a = (1.24 \times 10^3 \text{ eV} \bullet \text{nm}) / 600 \text{ nm} = 2.07 \text{ eV}$

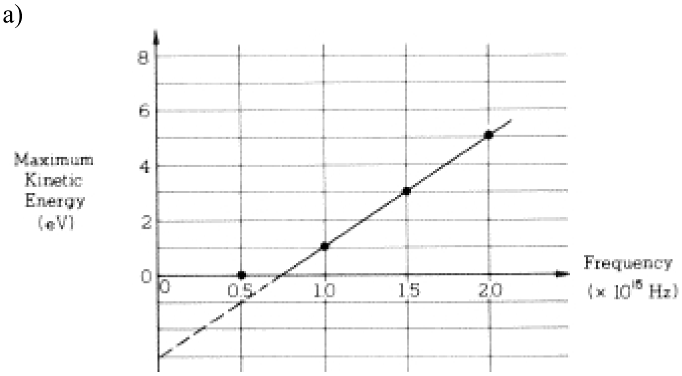
b) $E_c = E_a + E_b = 2.07 \text{ eV} + hc / \lambda_b = 2.07 + (1240 \text{ eV-nm}) / 300 \text{ nm} = 6.2 \text{ eV}$

$E_c = hc / \lambda_c$ … $6.2 = 1240 / \lambda_c$ … $\lambda_c = 200$ nm

c) For the range of frequencies input, only those that match the exact transitions will be absorbed. Only the A level transition of 600 nm wavelength matches the input light so that will be the one absorbed causing an upward jump along the A level line.

1980B3.

a)



b) From the graph, the threshold frequency occurs at zero K. This is about 0.75×10^{15} Hz

A result could be obtained using the work function. The y intercept of the graph is the work function (3 eV) and the work function is given by $\phi = hf_o$ … $3 \text{ eV} = (4.14 \times 10^{-15} \text{ eV} \bullet \text{s})\, f_o$
$f_o = 7.25 \times 10^{14}$ Hz

c) From above, the work function is 3 eV

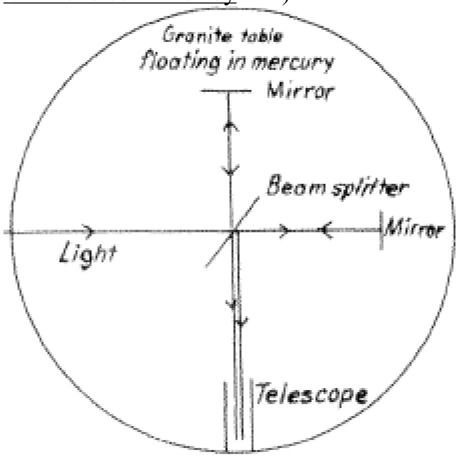
d) From $K = V_{stop}q$ .. and $K = hf - \phi$ … we have … $V_{stop}\, q = hf - \phi$
$V_{stop}(1e) = (4.14 \times 10^{-15} \text{ eV} \bullet \text{s})(2 \times 10^{15}) - 3 \text{ eV}$ … $V_{stop} = 5.28$ V

Alternatively, you could look up the K value from the graph corresponding to the given frequency, then plug into K=Vq and solve for V.

e.) There is most likely a magnetic field nearby to make the electrons move in circles.

1982B7.

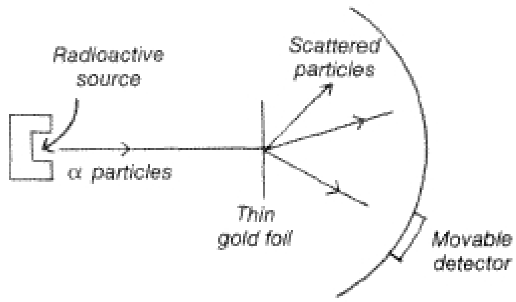
I. Michelson–Morley a)



b) Interference fringes produced by the two reflected beams were observed in the telescope. It was found that these fringes did not shift when the table was rotated

b) The experiment refuted the hypothesis that there is a "luminiferous ether" in space through which light propagates. The null result of the experiment indicated that the speed of light is constant, independent of its direction of propagation.

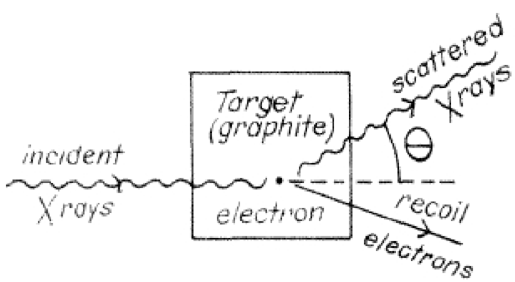
II. Rutherford scattering a)



b) The detector revealed that alpha particles were scattered in various directions as they passed through the gold foil. While most of the particles were deflected only slightly, a few were scattered through very large angles.

c) Rutherford concluded that an atom is mostly empty space, with all the positive charge being concentrated in a small, dense nucleus. This experiment refuted the alternative "plum pudding" model of the atom, according to which positive charges were distributed throughout the atom.

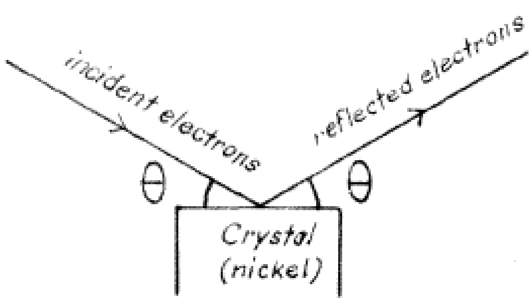
III. Compton scattering a)



b) Compton observed that x–rays were scattered through various angles as a result of their collision with electrons in the target. The larger the angle through which an x–ray was scattered, the more its wavelength had increased. The energy lost by the x–rays appeared as kinetic energy of the electrons.

c) The dependence of wavelength on scattering angle was explained by a model which treated x–rays as massless particles (photons) and used conservation of linear momentum and energy to analyze photon–electron collisions. A model of x–rays as electromagnetic waves without particle properties could not explain the experimental data. Compton concluded that electromagnetic radiation has particle properties as well as wave properties.

IV. Davisson–Germer experiment a)



b) Electrons were reflected from the crystal, with the angle of reflection equal to the angle of incidence. The fraction of electrons reflected was unusually large for certain values of θ. The same phenomenon has earlier been observed in connection with scattering of x–rays and explained as an interference effect.

c) It was concluded that electrons have wave properties, with their wavelength inversely proportional to their linear momentum, and that the mathematics of waves can be used to explain the behavior of what had been though to be "particles".

1983B6.

a) Using $K = hf - \phi$ for each set of results we get two equations:

$3 = h\,(1.5x10^{15}) - \phi$ … and … $1 = h\,(1x10^{15}) - \phi$

Substituting for the work function ϕ from 1 equation into the other and solving for h, we get h = 4 eV•s

b) Plug h back into either of the above equation to get ϕ = 3 eV

c) The energy of the green light is given by $E = hc / \lambda_{green}$ … E = (1240 eV-nm) / 500 nm = 2.48 eV.
The energy of the green light is less than the work function so no photoelectrons will be emitted.

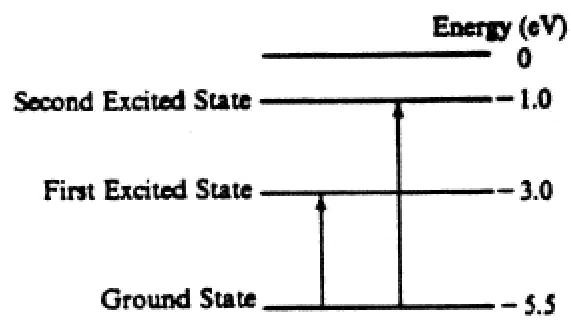
1985B6.

a) E = hf … 5.5 = ($4.14x10^{-15}$ eV-s) f … f = $1.33x10^{15}$ Hz

b) i. From the –1eV state, the following transitions could happen –1ev → –3eV → –5.5 →, or –1ev → –5.5eV, three different possible energy differences: 2eV, 2.5 eV and 4.5 eV
Using $E = hc / \lambda$ … with hc = 1240 eV-nm, and the energies above give the following wavelengths
λ_1 = 621 nm, λ_2 = 497 nm λ_1 = 276 nm

ii. The visible range is 400–700 nm, so the 1st and 2nd wavelengths are in that range.

c) The energies corresponding to the given wavelength are found with $E = hc / \lambda$ and are 1.24–4.97 eV. This range allows a transition to the first and second excited state but does not allow ionization because its not enough energy for ionization.



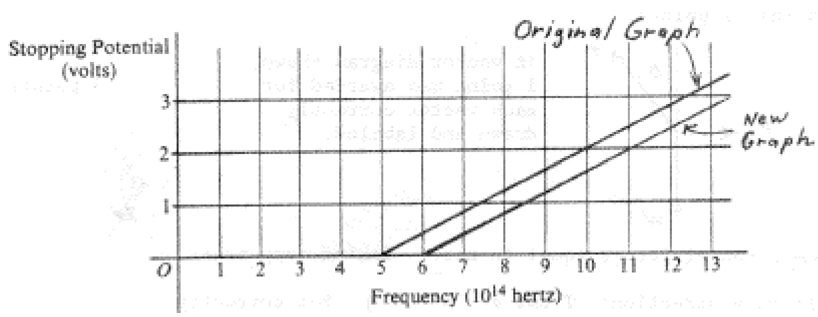
1987B6.

a) $K = V_{stop}\, q$ … (3V)(1e) = 3 eV

b) $K = hf - \phi$, $V_{stop}\, q = hf - \phi$ … is of the form y = mx + b, with the slope being h.
Slope = $6.4x10^{-34}$ J-s

c) From the above equation of the graph, the y intercept is the work function. We can extend the line down and use a ruler to determine the location, but since there is no scale below y=0 we are better with an alternative solution. At the threshold frequency, the K=0 since the work function is equal to the threshold frequency energy. So we can read the frequency off the graph where the energy is zero and use if the find the work function.
$\phi = hf_o = (6.4x10^{-34}\text{ J-s})(5x10^{14}) = 3.2x10^{-19}$ J.

d)



1988B6.

a) $c = f\lambda$ … $3x10^8 = f\,(500x10^{-9})$ … $f = 6x10^{14}$ Hz.
This is the threshold frequency since it is the minimum for photoelectric emission

b) $\phi = hf_o = 2.5$ eV

c) $K = E_{in} - \phi$ … $V_{stop}\, q = E_{in} - \phi$ … $(3)(1e) = E_{in} - 2.5$ eV … $E_{in} = 5.5$ eV

d) $E_{in} = hc / \lambda$ … $5.5 = (1240) / \lambda$ … $\lambda = 230$ nm

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1990B5.

a) Using energy conservation $U_e = K$ … $Vq = ½\, mv^2$ … $(12000)(1.6x10^{-19}) = ½\,(9.11x10^{-31})\, v^2$
$v = 6.5x10^7$ m/s

b) $I = q / t$ … $0.01 = Q / (1s)$ … $Q = 0.01\ C * (1e / 1.6x10^{-19}C)$ … $= 6.25x10^{16}$ e.

c) $K = Vq = E = hf$ $(12000\ v)(1\ e) = (4.14x10^{-15}\ eV\text{-}s)\ f$ … $f = 2.9x10^{18}$ Hz.

d) $c = f\,\lambda$ … $\lambda = 1x10^{-10}$ m

e) $p = h / \lambda = 6.6xx10^{-34} / 1x10^{-10} = 6.4 \times 10^{-24}$ kg-m/s

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1991B6.

a) $m\,\lambda_B = d\,x / L$ … $(1)\,(5.5x10^{-7}) = d\,(1.2x10^{-2}) / (0.85)$ $d = 3.9x10^{-5}$ m

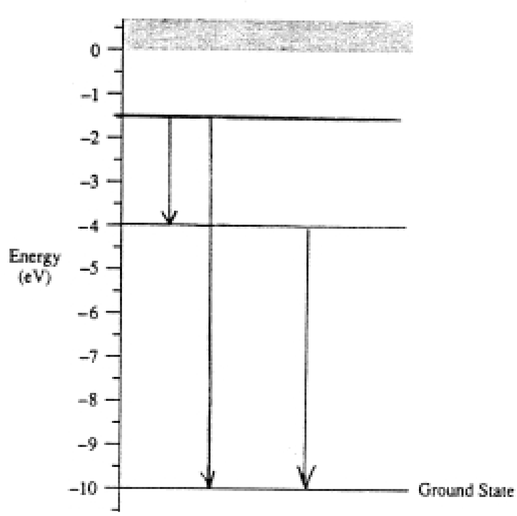
b) $m\,\lambda_a = d\,x / L$ … $(1)\,(4.4x10^{-7}) = (3.9x10^{-5})\, x / (0.85)$ $x = 9.6x10^{-3}$ m

c) $\phi = hf_o = hc / \lambda_o = (1240) / 600$ nm $= 2.1$ eV

d) $K = hc/\lambda - \phi = (1240)/440 - 2.1 = 0.75$ eV

1992B4.

a) Using $E = hc / \lambda$, with hc =1240 .. each energy is $E_1 = 6$ eV, $E_2 = 8.5$ eV



b) The above energies are absorptions from ground state (–10). So we use them as the energy differences needed to move up to the higher states and draw the lines accordingly.

c) emissions happen when moving down to lower energy levels.

d) ΔE of the two upper states = 2.5 eV. Use $E = hc / \lambda$ to determine the λ of that emission. $\lambda = 497$ nm

e) Since the visible spectrum is a range of 400 nm–700 nm, this λ is visible

1993B6.

a) The max frequency would be when all of the K is converted to x–ray energy.

$K = Vq$ … $E = hf$ … $(70000)(1.6\text{x}10^{-19}) = 6.63\text{x}10^{-34}\ f$ … $f = 1.69\text{x}10^{19}$ Hz.

b) $p = h / \lambda$ … $c = f\lambda$ … $p = hf / c$ … $p = 3.73\text{x}10^{-23}$ kg-m/s

c) From energy conservation, the total energy before must equal the energy after

$E_{photon(i)} = E_{photon(f)} + E_{electron}$ … $hf_i = hf_f + K_e$ … $(6.63\text{x}10^{-34})(1.69\text{x}10^{19}) = (6.63\text{x}10^{-34})(1.64\text{x}10^{19}) + K_e$

$K_e = 3.31\text{x}10^{-16}$ J

d) The energy of the recoiled electron can help us find its momentum. Using $K = ½\ mv^2$

$3.31\text{x}10^{-16}\ \text{J} = ½\ 9.11\text{x}10^{-31}\ v^2$ … $v = 2.7\text{x}10^7$ m/s

$p = (9.11\text{x}10^{-31})(2.7\text{x}10^7) = 2.46\text{x}10^{-23}$ kg-m/s

e) $p = h / \lambda$ … $2.46\text{x}10^{-23} = (6.6\text{x}10^{-34}) / \lambda$ … $\lambda = 2.7\text{x}10^{-11}$ m

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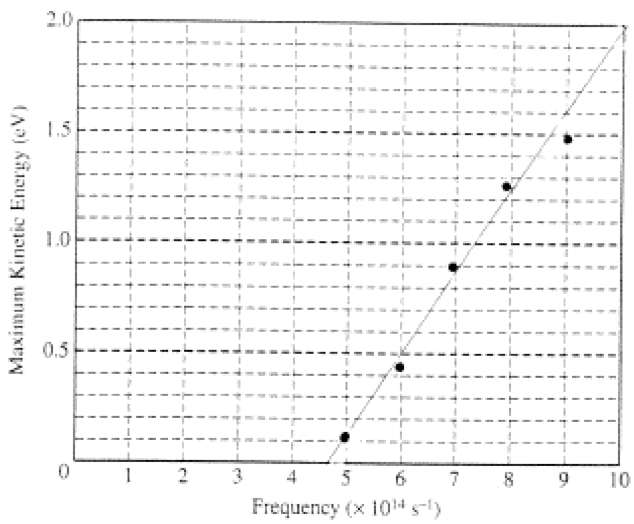
1994B3.

a)



From $K = hf - \phi$ which is an equation of form

$y = mx + b$

It is clear that the slope is h.

Use points on the line to find the slope. Only one of the data points is on the line, so we have to choose an arbitrary second point on the line to find the slope such as ($x=9\text{x}10^{14}$, $y = 1.6$ eV). Using this point and the first data point we get

$h = 3.75 \times 10^{-15}$ eV-s

1995B4.

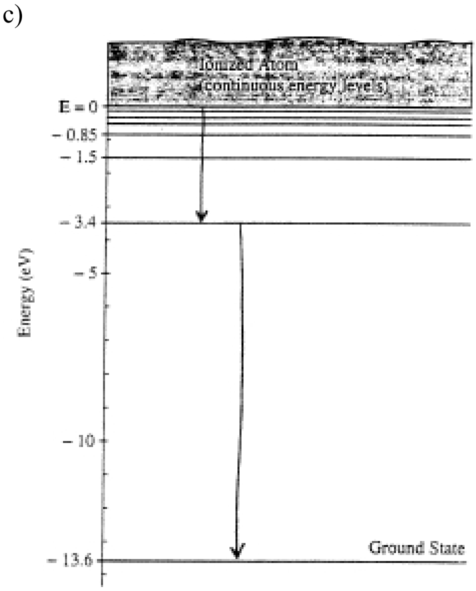
This question is a slightly different energy level question. Rather than absorbing light photons of energy to excite electrons in the atom, this atom captures a free electron. This electron is captured from outside the atom and enters from the highly excited E=0 state, and will have the full ionization energy of 13.6 eV. It will then undergo transitions to lower energy level states giving off its energy by emission of light photons from the atom as described in the problem.

a) $E = hc / \lambda$ … $10.2 = 1240 / \lambda$ … $\lambda = 122$ nm

b) i. There were two total energy emissions described in the problem. The first is unknown and the second is 10.2 eV which must have been a due to a drop to the ground state from the –3.4 eV state based on the energy level diagram provided. Since the second drop went from –3.4 eV → –13.6 eV … the first drop must have brought the electron to the –3.4 eV state and we know it started out at E=0 since it was initially captured from outside the atom. This means the first photon energy emitted must have been 3.4 eV to get it into that state and make the second drop described. … $E_a = 3.4$ eV

ii. $E = hf$ … $3.4 \text{ eV} = (4.14\text{x}10^{-15})\ f$ … $f = 8.2\text{x}10^{14}$ Hz.

c)



d) i. When more than the ionization energy is provided to an electron in a level, the electron will escape the atom and the excess energy above the ionization energy will be in the form of KE. 15 eV – 13.6 eV = 1.4 eV.

ii. Using the energy of the electron determine its speed. $K = \frac{1}{2} mv^2$ …
$(1.4\text{eV}*1.6\text{x}10^{-19} \text{ J / eV}) = \frac{1}{2}(9.11\text{x}10^{-31})\ v^2$ … $v = 7\text{x}10^5$ m/s

Then, $p = h / \lambda$ … $mv = h / \lambda$ … $(9.11\text{x}10^{-31})(7\text{x}10^5) = (6.63\text{x}10^{-34}) / \lambda$ … $\lambda = 1\text{x}10^{-9}$ m

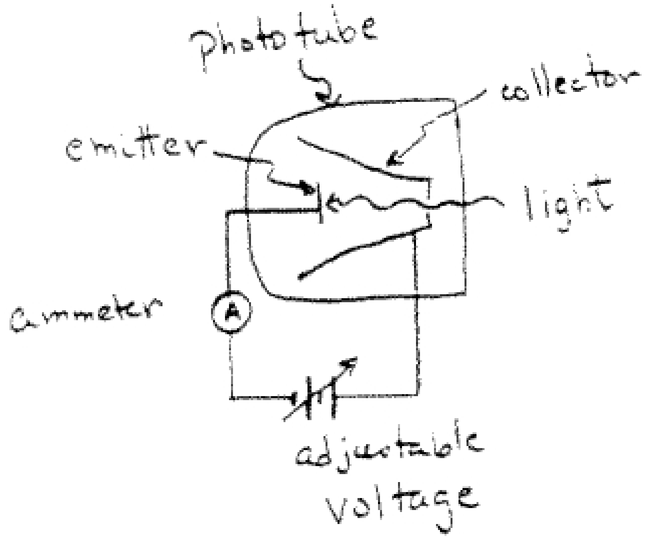
1997B6.

a&b)

i. Rutherford … see 1987B7

ii. Michelson–Morley … see 1987B7

iii. Photoelectric–effect



Observations:

The light creates a current in the circuit above a threshold frequency.

Above the cutoff frequency, the maximum kinetic energy of the electrons is proportional to the frequency.

The amount of current is proportional to the intensity of the light.

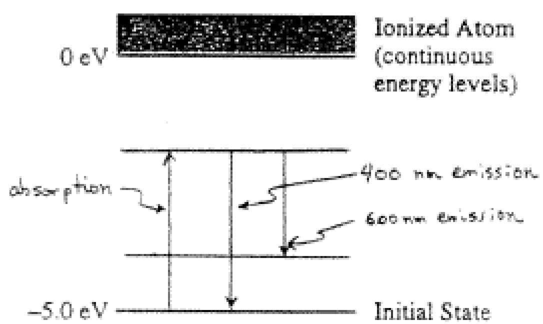
Conclusions:

Light is made of packets of energy (photons)

Light has a particle nature in addition to the wave nature

Different metals have different work functions to be overcome before electrons are released.

c)



d) Finding the energy of the 400 nm light.

E = hc / λ … E = 1240 / 400 nm … E = 3.1 eV

When this is absorbed in the –5eV state, it would move it up to the –1.9 eV state.

e) Find the energy of the 600 nm light

E = hc / λ … E = 1240 / 600 nm … E = 2.1 eV

From the diagram, we can see that the energy difference between the 400 nm λ drop and the 600 nm λ drop is the missing emission not accounted for. This energy difference is 1 eV. The λ of a 1 eV photon emission can be found with E = hc / λ … 1 eV = 1240 / λ … λ = 1240 nm, which is outside of the visible range (400–700)

1998B7.

a) Diffraction grating: Since the screen distance is 1 m and the first order line is at 0.428 m, the angle is not small and the small angle approximation cannot be used. Instead we find the angle with $\tan\theta$ and use $m\lambda = d \sin\theta$. First find d. d = 600 lines / mm = 1/600 mm / line = 0.00167 mm / line = $1.67\text{x}10^{-6}$ m / line.

$\tan\theta = o/a$ … $\tan\theta = 0.428 / 1$ … $\theta = 23°$ … Then, $m\lambda = d \sin\theta$ … (1) $\lambda = (1.67\text{x}10^{-6}) \sin 23°$
$\lambda = 6.57\text{x}10^{-7}$ m = 657 nm

b) First find the energy of the red light emission. $E = hc / \lambda$ … E = 1240/657 = 1.89 eV emitted

In the problem, the n=2 level energy state is given by $E_n = -13.6 / n^2 = E_2 = -13.6 / 2^2 = -3.4$ eV

Since the red light was an emission of 1.89 eV, this is the energy that was removed from the initial level to end up in the –3.4 eV level, → it must have originated in a higher energy level (less negative) which can be found by adding back that emitted energy –3.4 + 1.89 = – 1.51.
Plugging this back into the provided equation, $E_n = -13.6 / n^2$
$-1.51 = -13.6 / n^2$ … $n^2 = 9$, so n= 3 is the original level.

c) Referring to the calculation of d from part a .. d = 1/800 mm / line which is a smaller d value. Less d means $\sin\theta$ must increase so the angle is larger and the location of the line would be further out.

2000B5.

a) i. $K = V_{stop}\, q$ … K = (4.5V)(1e) = 4.5 eV
ii. $K = \frac{1}{2} mv^2$ … $4.5\text{eV}*(1.6\text{x}10^{-19}\text{ J/eV}) = \frac{1}{2}(9.11\text{x}10^{-31})v^2$ … $v = 1.26\text{x}10^{6}$ m/s

b) From $K = E_{in} - \phi$ … $4.5\text{ eV} = E_{in} - 2.3\text{ eV}$ … $E_{in} = 6.8$ eV
$E = hc / \lambda$ … $6.8 = 1240/\lambda$ … $\lambda = 182$ nm

c) $E_{min} = \phi$ … $hf_o = \phi$ … $(4.14\text{x}10^{-15})\, f_o = 2.3$ … $f_o = 5.56\text{x}10^{14}$ Hz.

2002B7.

a) $E = hc / \lambda$ … $(1.99 \text{ x } 10^{-25}\text{ J-m}) / 2\text{x}10^{-11}$ … $E = 9.9\text{x}10^{-15}$ J

b) $p = h / \lambda$ … $6.63\text{x}10^{-34} / 2\text{x}10^{-11}$ … $3.3\text{x}10^{-23}$ kg-m/s

c) Due to energy conservation, the total energy before must equal the total energy after. Since some of the energy after is given to the electron, the new photon would have less energy than the original. From $E = hc / \lambda$, less energy would mean a larger λ.

d) First determine the λ of the new photon. $\lambda_{new} = \lambda_{old} + \Delta\lambda$ … with $\Delta\lambda$ given in the problem as $2h/m_ec$
$\lambda_{new} = 2\text{x}10^{-11} + (2*6.63\text{x}10^{-34}/(9.11\text{x}10^{-31}*3\text{x}10^{8}))$ … $\lambda_{new} = 2.5\text{x}10^{-11}$ m

Using momentum conservation
$p_{photon(i)} = -p_{photon(new)} + p_{electron}$ (the new photon has – momentum since it moves in the opposite direction).

From this equation we get … $p_{electron} = p_{photon(i)} + p_{photon(new)}$ (with $p = h/\lambda$ for each photon)

$p_{electron} = (h/\lambda_i + h/\lambda_{new}) = 6.63\text{x}10^{-34}\,(1 / 2\text{x}10^{-11} + 1 / 2.5\text{x}10^{-11})$ … $= 6\text{x}10^{-23}$ kg-m/s

B2002B7.

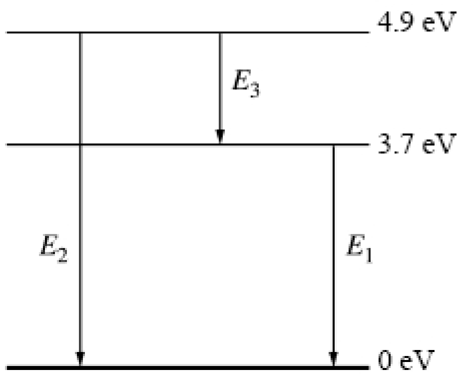
a) Determine the speed of the electrons … $K = \frac{1}{2} mv^2$ …

$3.7\text{eV}*(1.6\text{x}10^{-19}\text{J/eV}) = \frac{1}{2}(9.11\text{x}10^{-31})v^2$ … $v = 1.14\text{x}10^6$ m/s

$p = h / \lambda$ … $mv = h / \lambda$ … $(9.11\text{x}10^{-31})(1.14\text{x}10^6) = 6.63\text{x}10^{-34} / \lambda$ … $\lambda = 6.38\text{x}10^{-10}$ m

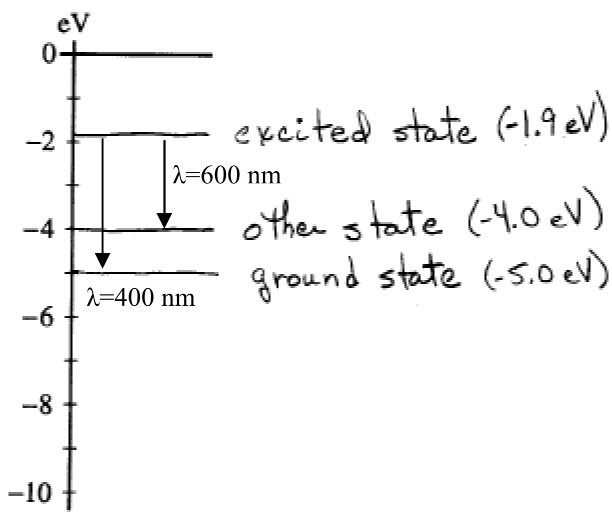
b) $E = hc / \lambda$ … $3.7 = 1240 / \lambda$ … $\lambda = 335$ nm

c)



$E_1 = 3.7$ eV
$E_2 = 4.9$ eV
$E_3 = 1.2$ eV

B2003B7.



a)

i. The ground state was given in the problem

ii. The first excited state corresponds to the absorption of the 400 nm photon. This energy is given by $E = hc / \lambda$ … $1240/400 = 3.1$ eV. Moving from a state of –5 eV and absorbing 3.1 eV moves you up to the higher excited state of –1.9 eV.

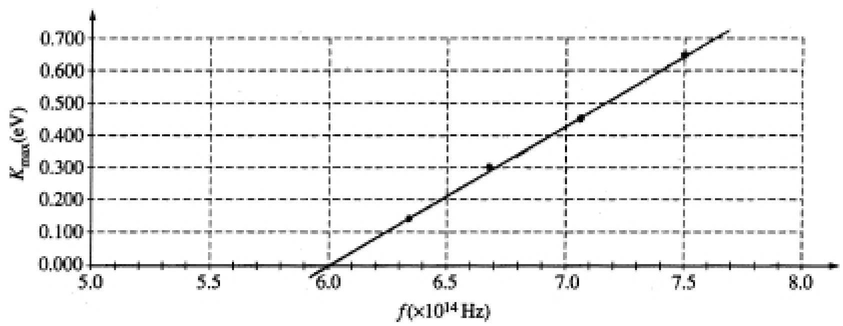
iii. After reaching the excited state, the electron makes two visible drops. It drops back down the ground state emitting the 400 nm photon, or it emits the 600 nm photon. This photon corresponds to an energy of 2.1 eV (found with $E = hc / \lambda$ again). Starting at –1.9eV and emitting 2.1 eV would put you in the –4eV level.

From the diagram above, the emission not yet analyzed is from the 'other' state to the ground state. That emission corresponds to an energy release of 1 eV. The λ of this emission can be found with $E = hc / \lambda$. Giving $\lambda = 1240$ nm. Since this is outside of the visible spectrum, it is not 'seen', but it does occur.

2004B6.

a) Based on the series and parallel configuration. M_1 = voltmeter M_2 = ammeter

b)

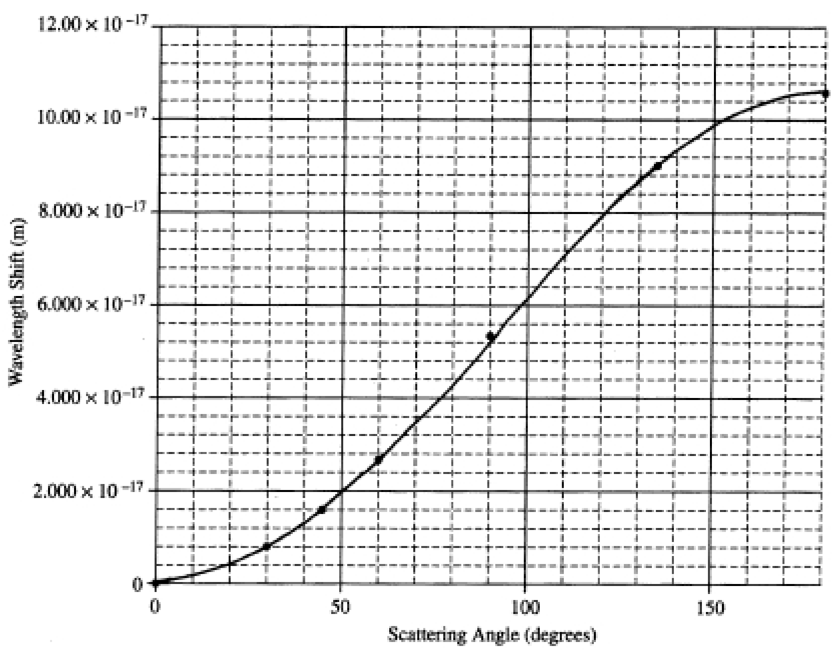


c) From $K = hf - \phi$ ($y=mx+b$) … h is found with the slope using the 1st and 3rd points since they are on the line. $h = 4.3\text{x}10^{-15}$ eV-s

d) The slope of the graph must be the same since its Planck's constant. A larger work function will required a larger threshold frequency and thus shift the graph to the right. Additionally, the y intercept is the work function and to increase the y intercept, the graph would likewise have to be shifted to the right.

B2004B6.

a)



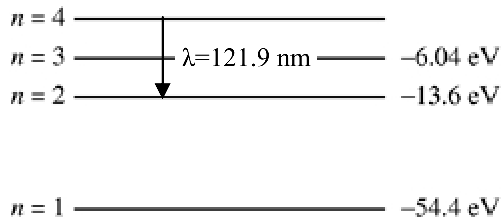
b) The graph is one of wavelength shift $\Delta\lambda$. Reading 120° from the graph gives a $\Delta\lambda$ value of $8\text{x}10^{-17}$. The new λ of the photon can be found with $\lambda' = \lambda + \Delta\lambda$, which gives us $\lambda' = 1.408\text{x}10^{-14}$ m

c) $p = h / \lambda$
$p = 4.71\text{x}10^{-20}$ kg-m/s

d) Using energy conservation. $E_{photon(i)} = E_{photon(f)} + E_{nucleus}$ … so the nucleus energy is the difference of the photon energy before and after found with hc / λ. $\Delta E = hc\,(1/\lambda_f - 1/\lambda_i) =$

$(1.22\text{x}10^{-25})\,(1 / 1.4\text{x}10^{-14} - 1 / 1.408\text{x}10^{-14}) =$ $8.08 \text{ x } 10^{-14}$ J.

2005B7.



a)
The energy of the λ drop shown is found with $E = hc / \lambda$
$E = (1240)/121.9 = 10.17$ eV, which means the n=4 state that it came from must have been –3.43 eV

b) $p = h / \lambda = 4.14\text{x}10^{-15} / 121.5 = 3.41\text{x}10^{-17}$ eV-s / nm

c) $K = E_{in} - \phi = 10.2 - 4.7 = 5.5$ eV

d) $K = Vq$ … $5.5 = V$ (1e) … $V = 5.5$ V

B2005B7.
a) $E = hc / \lambda$ … $E = 1240 / 450 = 2.8$ eV 2.8eV $*1.6\text{x}10^{-19}$J/eV $= 4.4\text{x}10^{-19}$ J

b) Using the beam power $W = Pt = (2.5\text{x}10^{-3}\text{ W})(5\text{min}*60\text{s/min}) = 0.75$ J
Total energy / energy of each photon = total # photons. 0.75 J / $4.4\text{x}10^{-19}$ J/photon $= 1.7\text{x}10^{18}$ photons.

c) $K=V_{stop}q$ … $½\ mv^2 = V_{stop}e$ … $½\ (9.11\text{x}10^{-31})v^2 = (0.86)(1.6\text{x}10^{-19})$ … $v = 5.5\text{x}10^5$ m/s

d) $p = h / \lambda$ … $mv = h / \lambda$ … $(9.11\text{x}10^{-31})(5.5\text{x}10^5) = (6.63\text{x}10^{-34}) / \lambda$ … $\lambda = 1.3$ nm

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2006B6.
a) $E = hc / \lambda$ … $E = 1240 / 15$ nm … $E = 82.7$ eV $*1.6\text{x}10^{-19}$J/eV $= 1.33\text{x}10^{-17}$ J

b) $K = ½\ mv^2$ … $1.33\text{x}10^{-17} = ½\ (9.11\text{x}10^{-31})\ v^2$ … $v = 5.4\text{x}10^6$ m/s
$p = h / \lambda$ … $mv = h / \lambda$ … $(9.11\text{x}10^{-31})(5.4\text{x}10^6) = 6.63\text{x}10^{-34} / \lambda$ … $\lambda = 1.35\text{x}10^{-10}$ m

c) A beam of electrons shot through a double slit produces a double slit diffraction pattern with bands of maximums and minimums. This demonstrates interference which is a wave property.
Davisson–Germer is also an experiment showing the wave nature of electrons. Since the question asks to describe the experiment, details of the experiment are required. See 1982B7 for the details.

2008B7.
a) $p = h / \lambda$ … $p = 6.63\text{x}10^{-34} / 0.038\text{ x}10^{-9}$ … $p = 1.74\text{x}10^{-23}$ kg-m/s

b) $p = mv$ … $1.74\text{x}10^{-23} = (9.11\text{x}10^{-31})\ v$ … $v = 1.91\text{x}10^7$ m/s … then $K= ½\ mv^2$ … $= 1.66\text{x}10^{-16}$ J

c) $K = V_{stop}\ q$ … $1.66\text{x}10^{-16} = V\ (1.6\text{x}10^{-19})$ … $V = 1.04\text{x}10^3$ V

d) Minimum frequency is when the incoming energy exactly equals the work function.
$hf_o = \phi$ … $(4.14\text{x}10^{-15})\ f_o = 4.5$ … $f_o = 1.09\text{x}10^{15}$ Hz.

B2008B7.

a) $E = hc / \lambda$ … 1.02×10^{6} eV = $1240 / \lambda$ … $\lambda = 1.2 \times 10^{-3}$ nm

b) $p = h / \lambda$ … $6.63 \times 10^{-34} / 1.2 \times 10^{-12}$ m … $= 5.43 \times 10^{-22}$ kg-m/s

c) From conservation of momentum, the momentum before is zero so the momentum after is also zero. To conserve momentum after, the momentum of the photon must be equal and opposite to the momentum of the Al nucleus. $p_{photon} = p_{nucleus} = m_{al}v_{al}$ … $5.43 \times 10^{-22} = 4.48 \times 10^{-26}\ v_{al}$ … $v_{al} = 1.21 \times 10^{4}$ m/s

d) $K = ½\ mv^2 = ½\ (4.48 \times 10^{-26})(1.21 \times 10^{4})^2 = 3.28 \times 10^{-18}$ J

2009B7.

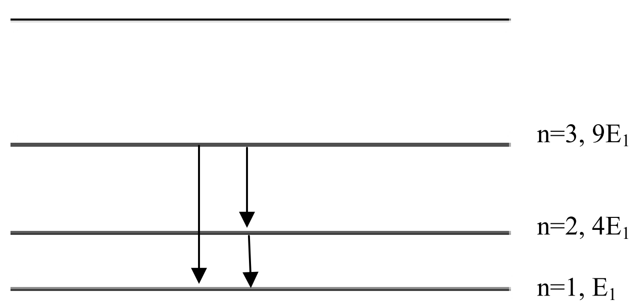
a) $p = h / \lambda$ … $mv = h / \lambda$ … $(9.11 \times 10^{-31})v = 6.63 \times 10^{-34} / 0.85 \times 10^{-9}$ … $v = 8.56 \times 10^{5}$ m/s
$K = ½\ mv^2 = ½\ (9.11 \times 10^{-31})(8.56 \times 10^{5})^2 = 3.34 \times 10^{-19}$ J

b) $K = E_{in} - \phi$ … $K = hc / \lambda - \phi$ … $3.34 \times 10^{-19} = 1.99 \times 10^{-25} / 250 \times 10^{-9} - \phi$ … $\phi = 4.62 \times 10^{-19}$ J = 2.89 eV

c) From $E = hc / \lambda$, a bigger λ means a smaller energy. The X emission of 400 nm is a smaller energy than the 250 nm photon. Since the photon was "created" from this transition, it must be an emission so we should go down energy levels with an energy difference larger than the X level difference. This would be transition d.

B2009B6.

a) From the given formula, the energy levels 1,2,3 correspond to E_1, $4E_1$, $9E_1$



b) Smallest frequency absorption corresponds to the smallest energy difference, which is n2–n1 = $3E_1$.
The frequency of this absorption can be determined from E=hf … $3E_1 = hf$ … $f = 3E_1 / h$

c) The second excited state is n=3, there are three possible transitions to the ground state shown above.

d) The highest energy emission corresponds to n3→n1 … $\Delta E = 8E_1$. The wavelength of this photon can be found with $E = hc / \lambda$ … $8E_1 = hc / \lambda$ … $\lambda = hc / 8E_1$

Supplemental.

a) Calculating the energies of each emission provided
$E_I = hc / \lambda_I$, $E_{II} = hc/ \lambda_{II}$ $\qquad E_I = 3.1$ eV $\quad E_{II} = 1.77$ eV
Transition III is the combination of the 2 above energies, $E_{III} = 4.87$ eV … finding the λ of this energy.
$E = hc / \lambda$ … 4.87 eV = $1240 / \lambda$ … $\lambda_{III} = 255$ nm.

b) $K = E_{in} - \phi = 4.87 - 2.1 = 2.77$ eV $\quad *(1.6 \times 10^{-19}$ J/eV$) = 4.43 \times 10^{-19}$ J

c) $K = ½\ mv^2$ … $4.43 \times 10^{-19} = ½\ (9.11 \times 10^{-31})\ v^2$ … $v = 9.86 \times 10^{5}$ m/s
$p = h / \lambda$ … $mv = h / \lambda$ … $(9.11 \times 10^{-31})(9.86 \times 10^{5}) = 6.63 \times 10^{-34} / \lambda$ … $\lambda = 7.38 \times 10^{-10}$ m

SECTION B – Nuclear Physics

1989B6.

a) $K = ½ mv^2$ … $½ (1.6726x10^{-27})(1.95x10^7)^2 = 3.18x10^{-13}$ J

b) $p_{before} = 0 = p_{after}$ → $m_p v_p = m_{he} v_{he}$ … $(1.6726x10^{-27})(1.95x10^7) = (6.6483x10^{-27})\ v_{he}$ … $v_{he} = 4.91x10^6$ m/s

c) $K = ½ mv^2$ … $½ (6.6483x10^{-27})(4.91x10^6)^2 = 8x10^{-14}$ J

d) The kinetic energy of both of the product particles comes from the conversion of mass in the reaction. The mass equivalent of the total energy of each particle is found with $E_{total} = m c^2$, with E_{total} the sum of the energies in (a) and (c). The results in a mass equivalent of $4.42x10^{-30}$ kg

e) The mass of the lithium nucleus would be the mass equivalence of the energy above, + the mass of each product resulting in $m_{Li} = 8.3253x10^{-27}$ kg

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1996B5.

a) The reaction can be written as follow: ? → $^{252}Fm_{100} + {}^4He_2$. For nucleons to add up properly, the original nucleus must have been $^{256}X_{102}$ (this is called Nobelium. FYI)

b) $K = ½ mv^2$ … $8.42x10^6$ eV $*1.6x10^{-19}$ J/eV = ½ (4.0026u*$1.66x10^{-27}$ kg) v^2 … $v = 2.014x10^7$ m/s

c) The kinetic energy comes from the conversion of mass to energy in the reaction. The mass before the reaction and the mass after the reaction are unequal, this is known as the mass difference. The energy equivalent of this mass difference contributes to the kinetic energy of the alpha particle.

d) Converting the alpha particle energy into mass equivalence. 8.42 Mev / (931 MeV /u) = 0.009 u.
Adding the masses of all the products. 252.08249 + 4.0026 + 0.009 u = 256.094 u

e) In B^- decay, a neutron turns into a proton and releases an electron beta particle. Since there is now one more proton, the atomic number increases by 1.

1999B4.

a) Since an alpha particle is $^4He_2$ to conserve the number of nuclei, Thallium must be $^{208}Tl_{81}$

b) i. $K = ½ mv^2$ … $6.09x10^6$ eV $(1.6x10^{-19}$ J/eV) = ½ $(6.64x10^{-27})\ v^2$ … $v = 1.71x10^7$ m/s

$p = mv = (6.64x10^{-27})(1.71x10^4) = 1.14x10^{-19}$ kg-m/s

ii. Momentum conservation … $p_{before} = 0 = p_{after}$ … $p_{alpha} = p_{Tl}$ … $m_a v_a = m_{Tl} v_{Tl}$
$(6.64x10^{-27})(1.71x10^7) = (208u * 1.66x10^{-27}$ kg/u) v_{Tl} … $v_{Tl} = 3.28x10^5$

$K = ½ mv^2 = ½ (208u * 1.66x10^{-27}$ kg/u) $(3.28x10^5)^2$ … $K = 1.86x10^{-14}$ J

c) The energy released is the energy of the products together which were found above and given in the problem $K_a + K_{Tl} = 9.93x10^{-13}$ J … The masses used above are for the masses for single particles so this energy corresponds to the energy of single particles. A mole is $6.02x10^{23}$ particles so multiply this individual energy by Avogadro's number to find the total energy in 1 mole = $5.98x10^{11}$ J.

2001B7.

a) Mass defect is the difference in mass comparing reactants to products. … $\Delta m = 0.0232$ u

b) Convert the mass difference to energy. 0.0232 u * 931 MeV / u = 21.6 MeV = $3.46\text{x}10^{-12}$ J

c) From the provided reaction, each reaction requires 3 deuterium atoms to release the energy above. Taking the total energy needed / the energy per reaction will give the # of reactions needed.

10^{20} J / $3.46\text{x}10^{-12}$ J/reaction → $2.89\text{x}10^{31}$ reactions.
Since each reactions uses 3 deuterium atoms, the total atoms needed is 3x this … = $8.68\text{x}10^{31}$ atoms.

d) Determine the mass of deuterium needed. $8.68\text{x}10^{31}$ atoms * 2.0141u = $1.748\text{x}10^{32}$ u
$1.746\text{x}10^{32}$ u * $1.66\text{x}10^{-27}$ kg / u = 290000 kg.

B2006B6.

a) $K = \frac{1}{2} mv^2$

b) $p = h / \lambda$ … $mv = h/\lambda$ … $\lambda = h/mv$

c) The total energy involved here is both the kinetic energy of the particles as well as the energy released from the annihilation of mass (mc^2). It's important to remember that the particles were moving before hand so we cannot simply ignore this kinetic energy as part of the total energy.
$E_{before} = KE_{electron + positron}$ + rest mass energy of the two particles … $2(\frac{1}{2} mv^2) + 2\, mc^2$
After the annihilation, there are two photon particles and they will split this total before energy in half so the energy of each photon is given by $mv^2 + mc^2$ …. And since in the problem it says $v << c$ this means the rest mass term will dominate the energy so the approximate photon energy is simply $E = mc^2$. You can leave out the kinetic energy term in this derivation but in reality this is part of the energy so you should at least state in the problem that you are omitting it because it is small relative to the rest mass energy.

d) $E = hc / \lambda$ … $mc^2 = hc / \lambda$ … $\lambda = h/mc$

e) Two photons must be produced in order to conserve momentum. Before the collision, there was zero net momentum since the same mass and velocity particles were moving in opposite directions, so after the collision there must also be zero net momentum. Since after the collision a photon will be moving off in one direction and has a mass equivalent and momentum, there much be another photon moving in the other direction with opposite momentum to conserve the net momentum of zero.

2007B7.

a) $E = mc^2 = (9.11\text{x}10^{-31})(3\text{x}10^8)^2 = 8.2\text{x}10^{-14}$ J * (1ev / $1.6\text{x}10^{-19}$ J) = $5.12\text{x}10^5$ eV

b) The total energy before is 2x the energy from part "a" since there are two particles of the same mass. After the annihilation, there are two photons that split this total energy, so each photon simply has the energy of one of the two particles = $5.12\text{x}10^5$ eV

c) $E = hc / \lambda$ … $5.12\text{x}10^5 = 1240 / \lambda$ … $\lambda = 2.42\text{x}10^{-3}$ nm

d) $p = h / \lambda$ … $4.14\text{x}10^{-15} / 2.42\text{x}10^{-3} = 1.71\text{x}10^{-12}$ eV-s / nm

B2007B7. This is the process of pair–production, creation of particles from energy

a) $E = mc^2 = (9.11 \times 10^{-31})(3 \times 10^8)^2 = 8.2 \times 10^{-14}$ J $*1\text{eV}/1.6 \times 10^{-19}$ J $= 5.12 \times 10^5$ eV

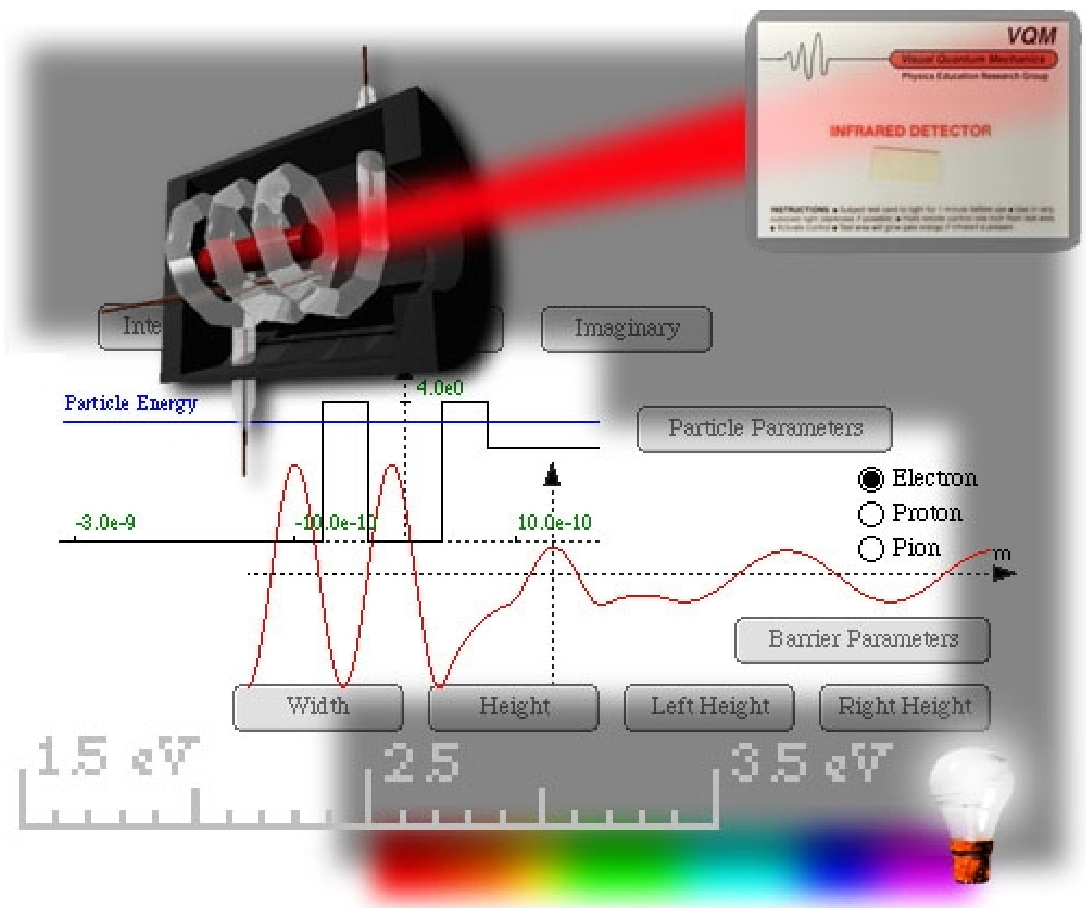
b) To cause pair production, 2x the energy of a single electron must be present since 2 'electron–like' particles are created. $2\ E_{electron} = 1.02 \times 10^6$ eV

c) $E = hc / \lambda$ … $1.02 \times 10^6 = 1240 / \lambda$ … 1.22×10^{-3} nm

d) $p = h / \lambda$ … $4.14 \times 10^{-15} / 1.22 \times 10^{-3}$ … 3.39×10^{-12} eV-s/nm

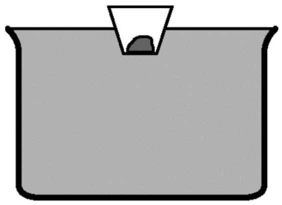
APPENDIX 2

Experimental Questions



AP LAB-BASED QUESTIONS

FLUIDS



BUOYANT FORCE/DENSITY (2010B2)
A large pan is filled to the top with oil of density ρ_o. A plastic cup of mass m_C , containing a sample of known mass m_S , is placed in the oil so that the cup and sample float, as shown above. The oil that overflows from the pan is collected, and its volume is measured. The procedure is repeated with a variety of samples of different mass, and the pan is refilled each time.

a. Draw and label the forces (not components) that act on the cup-sample system when it is floating on the surface of the oil.
b. Derive an expression for the overflow volume V_O (the volume of oil that overflows due to the floating system) in terms of ρ_0 , m_S , m_C , and fundamental constants. If you need to draw anything other than what you have shown in part **(a)** to assist in your solution, use the space below. Do NOT add anything to the figure in part **(a).**
Assume that the following data are obtained for the overflow volume V_O for several sample masses m_S

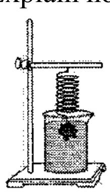
Sample mass m_S (kg)	0.020	0.030	0.040	0.050	0.060	0.070
Overflow volume V_0 (m^3)	29×10^{-6}	38×10^{-6}	54×10^{-6}	62×10^{-6}	76×10^{-6}	84×10^{-6}

c. Graph the data plotting the overflow volume as a function of sample mass. Place numbers and units on both axes. Draw a straight line that best represents the data.
d. Use the slope of the best-fit line to calculate the density of the oil.
e. What is the physical significance of the intercept of your line with the vertical axis?

BUOYANT FORCE/SPRING/DENSITY (2002B6) In the laboratory, you are given a cylindrical beaker containing a fluid and you are asked to determine the density ρ of the fluid. You are to use a spring of negligible mass and unknown spring constant k attached to a stand. An irregularly shaped object of known mass m and density $(D >> \rho)$ hangs from the spring. You may also choose from among the following items to complete the task.

_____ A metric ruler _____A stopwatch _____String

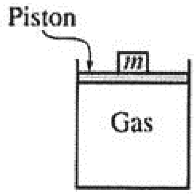
a. Explain how you could experimentally determine the spring constant k.



b. The spring-object system is now arranged so that the object (but none of the spring) is immersed in the unknown fluid, as shown.
Describe any changes that are observed in the spring-object system and explain why they occur.

c. Explain how you could experimentally determine the density of the fluid.
d. Show explicitly, using equations, how you will use your measurements to calculate the fluid density ρ. Start by identifying any symbols you use in your equations.

THERMODYNAMICS



Note: Figure not drawn to scale.

THERMODYNAMICS (2005B6b) You are given a cylinder of cross-sectional area A containing n moles of an ideal gas. A piston fitting closely in the cylinder is lightweight and frictionless, and objects of different mass m can be placed on top of it, as shown in the figure. In order to determine n, you perform an experiment that consists of adding 1 kg masses one at a time on top of the piston, compressing the gas, and allowing the gas to return to room temperature T before measuring the new volume V.

The data collected are given in the table below.

m (kg)	V (m^3)	$1/V$ (m^{-3})	P (Pa)
0	6.0×10^{-5}	1.7×10^{4}	
1	4.5×10^{-5}	2.2×10^{4}	
2	3.6×10^{-5}	2.8×10^{4}	
3	3.0×10^{-5}	3.3×10^{4}	
4	2.6×10^{-5}	3.8×10^{4}	

a. Write a relationship between total pressure P and volume V in terms of the given quantities and fundamental constants that will allow you to determine n.

You also determine that $A = 3.0 \times 10^{-4}\ m^2$ and $T = 300$ K.

b. Calculate the value of P for each value of m and record your values in the data table above.

c. Plot the data on the graph below, labeling the axes with appropriate numbers to indicate the scale.

d. Using your graph in part (c), calculate the experimental value of n.

ELECTROSTATICS

ELECTRIC FIELD (2011 B2b). You are to determine the magnitude and direction of the electric field at a point between two large parallel conducting plates. The two plates have equal but opposite charges, but it is not known which is positive and which is negative. The plates are mounted vertically on insulating stands.

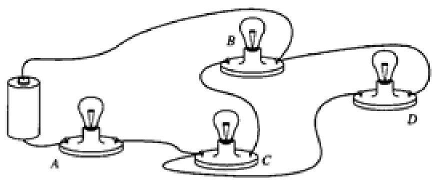
a. A small ball of known mass m, with a small charge $+q$ of known magnitude, is provided. The ball is attached to an insulating string. The additional laboratory equipment available includes only those items listed below, plus stands and clamps as needed. Choose the equipment you would use to make measurements needed to determine the magnitude and direction of the electric field between the two plates.

___ Wooden meterstick	___ Protractor	___ Screen
___ Spring scale	___ Stopwatch	___ Bright light
___ Metal rod	___ Camera (still or video)	___ Binoculars

b. Sketch a diagram of the experimental setup and label the pieces of equipment used.

c. Outline the experimental procedure you would use, including a list of quantities you would measure. For each quantity, identify the equipment you would use to make the measurement.

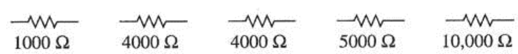
ELECTRICITY



DC CIRCUITS (1998B4) In the circuit shown, A, B. C, and D are identical light bulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each light bulb remains constant.

a. Draw a diagram of the circuit in the box below. **Use and label** the resistors symbols as A, B. C, and D to refer to the corresponding light bulbs.
b. List the bulbs in order of brightness, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. **Justify your answer.**
c. Bulb D is then removed from its socket.
i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. **Justify your answer.**
ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. **Justify your answer.**

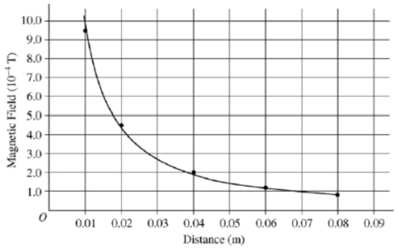
CIRCUITS (2003Bb2) A student is asked to design a circuit to supply an electric motor with 1.0 mA of current at 3.0 V potential difference.
a. Determine the power to be supplied to the motor.
b. Determine the electrical energy to be supplied to the motor in 60 s.
c. Operating as designed above, the motor can lift a 0.012 kg mass a distance of 1.0 m in 60 s at constant velocity. Determine the efficiency of the motor.
To operate the motor, the student has available only a 9.0 V battery to use as the power source and the following five resistors.



d. In the space below, complete a schematic diagram of a circuit that shows how one or more of these resistors can be connected to the battery and motor so that 1.0 mA of current and 3.0 V of potential difference are supplied to the motor. Be sure to label each resistor in the circuit with the correct value of its resistance.

MAGNETISM

MAGNETIC FIELD 1 (2008 B3b) A student is measuring the magnetic field generated by a long, straight wire carrying a constant current. A magnetic field probe is held at various distances *d* from the wire, as shown above, and the magnetic field is measured. The graph below shows the five data points the student measured and a best-fit curve for the data.

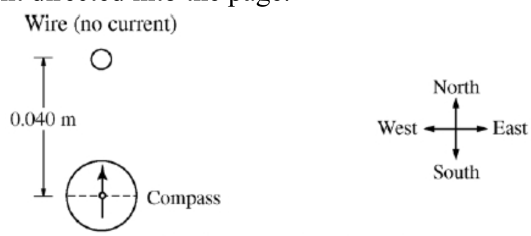


Unfortunately, the student forgot about Earth's magnetic field, which has a value of $5.0\text{x}10^{-5}$ T at this location and is directed north.

a. On the graph, plot new points for the field due only to the wire.

b. Calculate the value of the current in the wire.

Another student, who does not have a magnetic field probe, uses a compass and the known value of Earth's magnetic field to determine the magnetic field generated by the wire. With the current turned off, the student places the compass 0.040 m from the wire, and the compass points directly toward the wire as shown below. The student then turns on a 35 A current directed into the page.



Note: Figure not drawn to scale.

c. On the compass, sketch the general direction the needle points after the current is established.

d. Calculate how many degrees the compass needle rotates from its initial position pointing directly north.

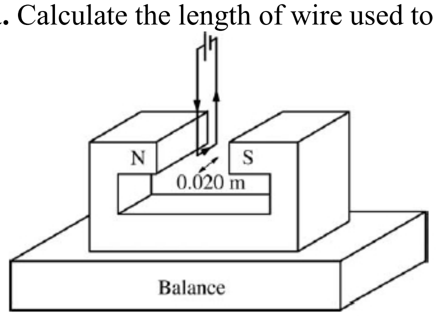
The wire is part of a circuit containing a power source with an emf of 120 V and negligible internal resistance.

e. Calculate the total resistance of the circuit.

f. Calculate the rate at which energy is dissipated in the circuit.

MAGNETIC FIELD 2 (2008 B3) A rectangular wire loop is connected across a power supply with an internal resistance of 0.50 Ω and an emf of 16 V. The wire has resistivity $1.7\text{x}10^{-8}$ Ω.m and cross-sectional area $3.5\text{x}10^{-9}$ m^2. When the power supply is turned on, the current in the wire is 4.0 A.

a. Calculate the length of wire used to make the loop.



Note: Figure not drawn to scale.

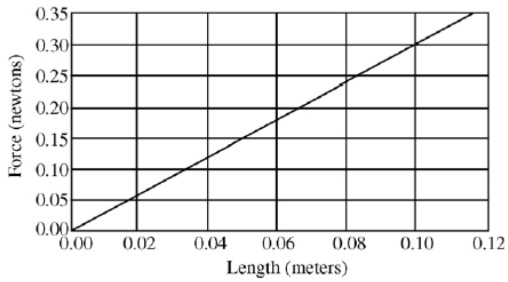
The wire loop is then used in an experiment to measure the strength of the magnetic field between the poles of a magnet. The magnet is placed on a digital balance, and the wire loop is held fixed between the poles of the magnet, as shown below. The 0.020 m long horizontal segment of the loop is midway between the poles and perpendicular to the direction of the magnetic field. The power supply in the loop is turned on, so that the 4.0 A current is in the direction shown.

b. In which direction is the force on the magnet due to the current in the wire segment?

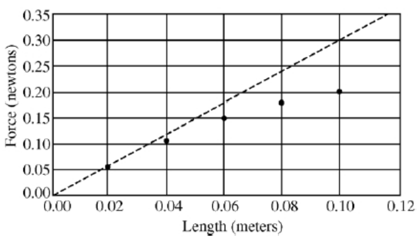
____Upward ____Downward Justify your answer.

c. The reading on the balance changed by 0.060 N when the power supply was turned on. Calculate the strength of the magnetic field.

Suppose that various rectangular loops with the same total length of wire as found in part (a) were constructed such that the lengths of the horizontal segments of the wire loops varied between 0.02 m and 0.10 m. The horizontal segment of each loop was always centered between the poles, and the current in each loop was always 4.0 A. The following graph represents the theoretical relationship between the magnitude of the force on the magnet and the length of the wire.



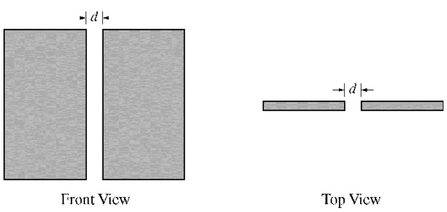
d. On the graph, sketch a possible relationship between the magnitude of the force on the magnet and the length of the wire segment if the wire segments were misaligned and placed at a constant nonperpendicular angle to the magnetic field, as shown below:



e. Suppose the loops are correctly placed perpendicular to the field and the following data are obtained. Describe a likely cause of the discrepancy between the data and the theoretical relationship.

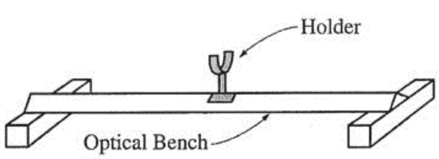
OPTICS

DOUBLE-SLIT 1. (2005B4) Your teacher gives you a slide with two closely spaced slits on it. She also gives you a laser with a wavelength $\lambda = 632$ nm. The laboratory task that you are assigned asks you to determine the spacing between the slits. These slits are so close together that you cannot measure their spacing with a typical measuring device.
(a) From the list below, select the additional equipment you will need to do your experiment by checking the line next to each item.
_____Meterstick _____Ruler _____Tape measure _____Light-intensity meter
_____Large screen _____Paper _____Slide holder _____Stopwatch
b. Draw a labeled diagram of the experimental setup that you would use. On the diagram, use symbols to identify carefully what measurements you will need to make.
c. Sketch a graph of intensity versus position that would be produced by your setup, assuming that the slits are very narrow compared to their separation.
d. Outline the procedure that you would use to make the needed measurements, including how you would use each piece of the additional equipment you checked in **a.**
e. Using equations, show explicitly how you would use your measurements to calculate the slit spacing.



DOUBLE -SLIT 2. (20011B3) Two metal strips are brought together until their edges are separated by a small distance *d*, forming a narrow slit, as represented. You are to design a laboratory experiment to determine the width of the slit.
a. From the following list of available equipment, check those additional items you would use for the purpose of determining the slit width *d*.

___ Laser pointer (λ = 635 nm) ___ Meterstick ___ Mirror ___ Metric ruler
___ Screen ___ Prism ___ Filament lamp ___ Stopwatch
b. Sketch a diagram of your experimental setup and label the pieces of equipment that would be used.
c. Outline the experimental procedure you would use, including a list of quantities you would measure. For each quantity, identify the equipment you would use to make the measurement.
d. Explain how you would calculate the slit width *d* by using the measured quantities identified in (c).
e. Suppose the separation *d* between the strips was increased, but everything else was kept the same. What changes would you expect to observe? Explain your reasoning.



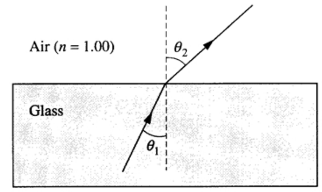
MIRRORS (2003B4) In your physics lab, you have a concave mirror with radius of curvature r = 60 cm. You are assigned the task of finding experimentally the location of a lit candle such that the mirror will produce an image that is 4 times the height of the lit candle.

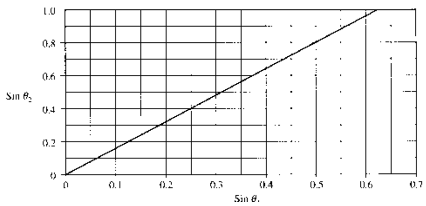
You have an optical bench, which is a long straight track as shown above. Objects in holders can be attached at any location along the bench. In addition to the concave mirror and the lit candle in holders, you also have the following equipment.
_____convex mirror in holder _____concave lens in holder _____ruler
_____convex lens in holder _____meterstick _____ screen in holder
a. Briefly list the steps in your procedure that will lead you to the location of the lit candle that produces the desired image. Include definitions of any parameters that you will measure.
b. On the list of equipment before part **a.** place check marks beside each additional piece of equipment you will need to do this experiment.
c. Draw a ray diagram of your lab setup in part a. to show the locations of the candle, the mirror, and the image.
d. Check the appropriate spaces below to indicate the characteristics of your image.
_____real _____upright _____larger than object
_____virtual _____inverted _____smaller than object

e. You complete your assignment and turn in your results to your teacher. She tells you that another student, using equipment from the same list, has found a different location for the lit candle. However, she tells both of you that the labs were done correctly and that neither experiment need be repeated. Explain why both experiments can be correct.

f. Draw a ray diagram of your lab setup for part (e) to show the locations of the candle, the optical device, and the image.

INDEX OF REFRACTION 1. (2001B4) In an experiment a beam of red light of wavelength 675 nm in air passes from glass into air, as shown. The incident and refracted angles are θ_1 and θ_2 , respectively. In the experiment, angle θ_2 is measured for various angles of incidence θ_1, and the sines of the angles are used to obtain the line shown in the following graph.





a. Assuming an index of refraction of 1.00 for air, use the graph to determine a value for the index of refraction of the glass for the red light. Explain how you obtained this value.

b. For this red light, determine the following.

i. The frequency in air **ii.** The speed in glass **iii.** The wavelength in glass

c. The index of refraction of this glass is 1.66 for violet light, which has wavelength 425 nm in air.

i. Given the same incident angle θ_1, show on the ray diagram on the previous page how the refracted ray for the violet light would vary from the refracted ray already drawn for the red light.

ii. Sketch the graph of sin θ_2 versus sin θ_1 for the violet light on the figure on the previous page that shows the same graph already drawn for the red light.

d. Determine the critical angle of incidence θ_c, for the violet light in the glass in order for total internal reflection to occur.

INDEX OF REFRACTION 2. (2006 B4) A student performs an experiment to determine the index of refraction n of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence θ_i in air and corresponding angles of refraction θ_r in glass. The measurements of the angles for five trials are given in the table below.

Trial	θ_i	θ_2		
1	30°	20°		
2	40°	27°		
3	50°	32°		
4	60°	37°		
5	70°	40°		

a. Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

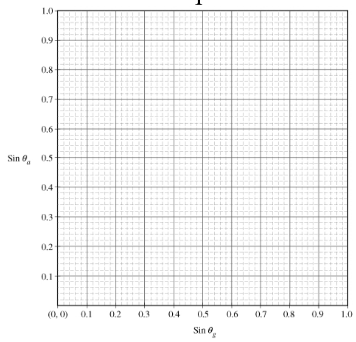
b. Plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.

c. Using the graph, calculate the index of refraction of the glass slab.

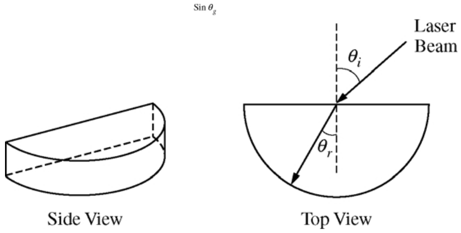
INDEX OF REFRACTION 3. (2007 B6b) A student is asked to determine the index of refraction of a glass slab. She conducts several trials for measurement of angle of incidence θ_a in the air versus angle of refraction θ_g in the glass at the surface of the slab. She records her data in the following table. The index of refraction in air is 1.0.

Trial #	θ_g (degrees)	θ_a (degrees)	Sin θ_g	Sin θ_a
1	5.0	8.0	0.09	0.14
2	15	21	0.26	0.36
3	25	39	0.42	0.63
4	35	56	0.57	0.83

a. Plot the data points on the axes below and draw a best-fit line through the points.



b. Calculate the index of refraction of the glass slab from your best-fit line.
c. Describe how you could use the graph to determine the critical angle for the glass-air interface. Do not use the answer to the part (b) for this purpose.
d. On the graph in (a), sketch and label a line for a material of higher index of refraction.



INDEX OF REFRACTION 4. (2013B3) A student is asked to experimentally determine the index of refraction of the semicircular block of transparent plastic shown in the figure above. The student aims a red laser beam of wavelength λ = 632 nm at the center of the flat side of the block, as shown. The ray is refracted from air into the plastic and strikes the semicircular side of the block perpendicularly.

The student uses a protractor to aim the laser at several different angles of incidence θ_i between 0° and 90° and to measure the angles of refraction θ_r. The student's data are given in the table below.

θ_i	0°	15°	30°	45°	60°	75°
θ_r	0°	10°	21°	30°	37°	44°
$\sin\theta_i$	0	0.26	0.50	0.71	0.87	0.97
$\sin\theta_r$	0	0.17	0.36	0.50	0.60	0.70

a. Plot data that will allow the index of refraction of the plastic to be calculated from a straight line that represents the data. Clearly label the axes, including the scales.
b. On your graph, draw a straight line that best represents the data. Use the slope of the line to determine the index of refraction of the plastic.
The student now wants to confirm the result obtained in part (b) by using the critical angle for the plastic.
c. Describe one experimental method the student can use to measure the critical angle. Indicate how the index of refraction can be determined from this measurement.

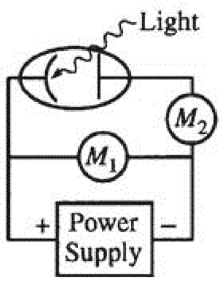
LENSES (2007B6) You are asked to experimentally determine the focal length of a converging lens.
a. Your teacher first asks you to estimate the focal length by using a distant tree visible through the laboratory window. Explain how you will estimate the focal length.
To verify the value of the focal length, you are to measure several object distances s_o and image distances s_i using equipment that can be set up on a tabletop in the laboratory.
b. In addition to the lens, which of the following equipment would you use to obtain the data?
____Lighted candle ____ Candleholder ____ Desk lamp ____ Plane mirror
____ Vernier caliper ____ Meterstick ____ Ruler ____ Lens holder
____ Stopwatch ____ Screen ____ Diffraction grating

c. Sketch the setup used to obtain the data, labeling the lens, the distances s_o and s_i and the equipment checked in part (b).
You are to determine the focal length using a linear graph of $1/s_i$ versus $1/s_o$. Assume that you obtain the following data for object distance s_o and image distance s_i.

Trial #	s_o (m)	s_i (m)	$1/s_o$ (m^{-1})	$1/s_i$ (m^{-1})
1	0.40	1.10	2.5	0.91
2	0.50	0.75	2.0	1.3
3	0.60	0.60	1.7	1.7
4	0.80	0.50	1.2	2.0
5	1.20	0.38	0.83	2.6

d. Plot the points in the last two columns of the table above and draw a best-fit line through the points.
e. Calculate the focal length from the best-fit line.

MODERN PHYSICS



PHOTOELECTRIC EFFECT (2004B6) A student performs a photoelectric effect experiment in which light of various frequencies is incident on a photosensitive metal plate. This plate, a second metal plate, and a power supply are connected in a circuit, which also contains two meters, M_1, and M_2, as shown above. The student shines light of a specific wavelength λ onto the plate. The voltage on the power supply is then adjusted until there is no more current in the circuit, and this voltage is recorded as the stopping potential V_s.

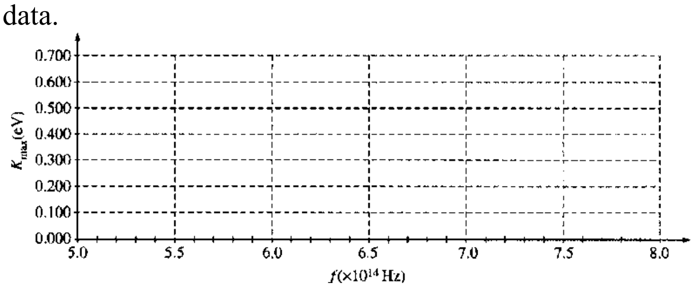
The student then repeats the experiment several more times with different wavelengths of light. The data, along with other values calculated from it, are recorded in the table below.

K_{max}(eV)	0.65	0.45	0.30	0.15
λ(m)	4.00×10^{-7}	4.25×10^{-7}	4.50×10^{-7}	4.75×10^{-7}
V_S(volts)	0.65	0.45	0.30	0.15
f(Hz)	7.50×10^{14}	7.06×10^{14}	6.67×10^{14}	6.32×10^{14}

a. Indicate which meter is used as an ammeter and which meter is used as a voltmeter by checking the appropriate spaces below.

	M_1	M_2
Ammeter	_____	_____
Voltmeter	_____	_____

b. Use the data above to plot a graph of K_{max} versus f on the axes below, and sketch a best-fit line through the data.

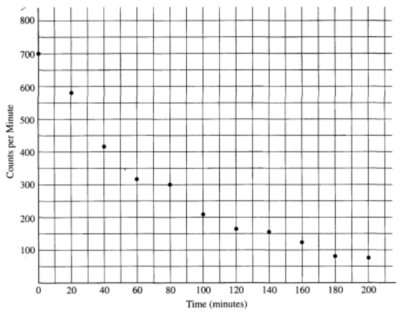


c. Use the best-fit line you sketched in part (b) to calculate an experimental value for Planck's constant.
d. If the student had used a different metal with a larger work function, how would the graph you sketched in part (b) be different? Explain your reasoning.

RADIOACTIVITY (1999B4) You use a Geiger counter to measure the decay of a radioactive sample of bismuth 212 over a period of time and obtain the following results.

Time (min)	0	20	40	60	80	100	120	140	160	180	200
Counts/minute	702	582	423	320	298	209	164	154	124	81	79

a. Your results are plotted on the following graph. On the graph, draw an estimate of a best-fit curve that shows the radioactive counts as a function of time.



b. From the data or from your graph, determine the half-life of this isotope. Explain how you arrived at your answer.

c. The bismuth isotope decays into thallium by emitting an alpha particle according to the following equation:

$$^{212}_{83}Bi \rightarrow Tl + \alpha$$

Determine the atomic number Z and the mass number A of the thallium nuclei produced

d. The mass of the alpha particle is 6.64×10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.

i. Determine the momentum of the alpha particle.

ii. Determine the kinetic energy of the recoiling thallium nucleus.

e. Determine the total energy released during the decay of 1 mole of bismuth 212.