UNIVERSITY OF SASKATCHEWAN

Department of Physics and Engineering Physics

Physics 117.3

FINAL EXAMINATION

April 11, 2019 Time: 3 hours

NAME: ___________________SOLUTIONS___________________ STUDENT NO.: ____________

(Last) **Please Print** (Given)

LECTURE SECTION (please check the appropriate box):

❑ 01 Dr. Y. Yao

❑ 02 B. Zulkoskey

INSTRUCTIONS:

1. This is a closed book exam.
2. The test package includes a test paper (this document), an exam booklet, a formula sheet, a scratch card and an OMR (OpScan / bubble) sheet. The test paper consists of 12 pages, including this cover page. **It is the responsibility of the student to check that the test paper is complete**.
3. Only a basic scientific calculator (e.g. Texas Instruments TI-30X series, Hewlett-Packard HP 10s or 30S) may be used. Graphing or programmable calculators, or calculators with communication capability, or calculators in smart phones are **not** allowed.
4. Enter your name and student number on the cover of the test paper and check the appropriate box for your lecture section. Also enter your name on the exam booklet and scratch card.
5. Enter your name and NSID on the OMR (OpScan / bubble) sheet.
6. The test paper, the exam booklet, the formula sheet, the scratch card, and the OMR (OpScan / bubble) sheet must all be submitted.
7. No test materials will be returned.

QUESTION #	MAX. MARKS	MARKS
A1-20	20	
B21-24	8	
B25-28	8	
B29-32	8	
B33-36	8	
B37-40	8	
B41-44	8	
MARK	out of 60:	

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PART A

For each of the following questions in Part A, enter the most appropriate response on the OMR (OpScan / bubble) sheet. Use the exam booklet for your rough work.

E

A1. A wood block floats in a container that is partially filled with water. The container is then sealed and pressurized so that the air in the container is now at a pressure that is twice that of atmospheric pressure. What will happen to the wood block?

(A) It will rise an amount corresponding to 50% of the volume initially submerged in water.
(B) It will rise an amount corresponding to 25% of the volume initially submerged in water.
(C) It will sink an amount corresponding to 50% of the volume initially above water.
(D) It will sink an amount corresponding to 25% of the volume initially above water.
(E) It will remain at the same level.

Pascal's Principle: same change of pressure throughout the system.

B

A2. The volume flow rate of blood through the average human aorta, of radius 1.0 cm, is about 90 cm³/s. What is the speed of the blood flow through the aorta?

(A) 14 cm/s (B) 29 cm/s (C) 32 cm/s (D) 37 cm/s (E) 44 cm/s

$Q = Av \Rightarrow v = \frac{Q}{A} = \frac{90\,cm^3/s}{\pi(1.0\,cm)^2} = 28.6\,cm/s = 29\,cm/s$

D

A3. A concrete pillar of radius R compresses a distance ΔL when it is supporting a load force of F. If you wish to use a different pillar, of the same length, and have it compress a distance of ½ ΔL when a load F is applied, what must be the radius of the new pillar?

(A) ¼ R (B) ½ R (C) $2R$ (D) $\sqrt{2}\,R$ (E) $4R$

$\frac{F}{A} = Y\frac{\Delta L}{L} \Rightarrow \frac{F}{\pi R^2} = Y\frac{\Delta L}{L} \Rightarrow \sqrt{\frac{FL}{\pi Y \Delta L}} = R \Rightarrow \frac{R_2}{R_1} = \sqrt{\frac{\Delta L_1}{\Delta L_2}} = \sqrt{\frac{1}{1/2}} = \sqrt{2}$

A

A4. A block-spring system vibrating on a frictionless, horizontal surface with an amplitude of 6.0 cm has a total energy of 12 J. If the block is replaced by one having twice the mass of the original block and the amplitude of the motion is reduced to 3.0 cm, what is the energy of the more massive system?

(A) 3 J (B) 6 J (C) 12 J (D) 18 J (E) 24 J

$E = \frac{1}{2}kA^2 = \frac{1}{2}mv_{max}^2$ no change in k (same spring) $E_2 = \frac{1}{2}k\left(\frac{A_1}{2}\right)^2 = \frac{1}{4}\left(\frac{1}{2}kA_1^2\right) = \frac{1}{4}E_1 = 3\,J$

D

A5. Which one of the following changes will **not** affect the frequency of sound produced by a vibrating guitar string?

(A) decreasing the vibrating length of the string
(B) increasing the tension in the string
(C) replacing the string with one that has a smaller linear mass density
(D) displacing the string in such a way that it has a larger amplitude of vibration
(E) replacing the string with one that has a larger mass

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A6. While driving at a constant speed on the highway, you notice an ambulance approaching you from behind. The ambulance is also moving at a constant speed and its siren is producing sound of frequency f. Which one of the following statements is correct?

E

(A) As the ambulance approaches you, both the frequency and the intensity of the sound that you hear steadily increases.
(B) As the ambulance approaches you, the frequency of sound that you hear increases, but the intensity remains constant.
(C) As the ambulance approaches you, the frequency of sound that you hear remains constant at f, but the intensity steadily increases.
(D) As the ambulance approaches you, both the frequency and the intensity of the sound that you hear remain constant.
(E) As the ambulance approaches you, the frequency of sound that you hear remains constant at a value greater than f, and the intensity steadily increases.

source approaching observer, $f_o > f$ $I \uparrow$ as separation distance $\downarrow$

A7. Which one of the following types of electromagnetic waves have the shortest wavelengths?

E

(A) radio waves (B) infrared light (C) visible light
(D) ultraviolet light (E) gamma rays

A8. The index of refraction for water is about 4/3. What happens to light when it travels from air into water?

$n = \frac{c}{v} = \frac{f\lambda_o}{f\lambda}$

C

(A) Its speed increases to 4c/3, and its wavelength increases by a factor of 4/3.
(B) Its speed increases to 4c/3, and its frequency increase by a factor of 4/3.
(C) Its speed decreases to 3c/4, and its wavelength decreases by a factor of 3/4.
(D) Its speed decreases to 3c/4, and its frequency decreases by a factor of 3/4.
(E) Its speed and frequency remain the same.

A9. Consider a beam of light, initially travelling in air, that strikes a horizontal water surface at an angle of incidence of $0° < \theta < 90°$. Which one of the following statements is correct?

E

(A) If the angle of incidence is greater than the critical angle, then all of the light reflects from the water surface.
(B) Regardless of the angle of incidence, all of the light transmits into the water.
(C) Regardless of the angle of incidence, all of the light reflects from the water surface.
(D) If the angle of incidence is less than the critical angle, then all of the light reflects from the water surface.
(E) The light is partially reflected and partially transmitted.

A10. Suppose Young's double-slit experiment is performed in air using red light and then the apparatus is immersed in water. What happens to the interference pattern on the screen?

B

(A) The bright and dark fringes stay in the same locations, but the contrast is reduced.
(B) The bright fringes are closer together.
(C) The color shifts toward ~~blue~~. infrared
(D) The bright fringes are farther apart.
(E) No change happens in the interference pattern.

$n_{water} > n_{air}$

$v\downarrow, \lambda\downarrow$

$m\lambda = d\sin\theta$, $\sin\theta\downarrow$, $\theta\downarrow$ pattern compresses

A11. Suppose you have a light source that is emitting light of only two wavelengths, 400 nm (violet) and 600 nm (red). You shine the light from the source through a set of parallel, evenly-spaced slits and view the resulting pattern on a screen. Is it possible for there to be locations on the screen that are illuminated by both colours at the same time?

D

(A) No, this is not possible.
(B) Yes, but only if the light passes through more than 10 slits.
(C) Yes, but only if the two wavelengths are of exactly the same intensity.
(D) Yes, but only at locations where the order of the red fringe, m_{red}, is 2/3 m_{violet}.
(E) Yes, but only at locations where the order of the red fringe m_{red}, is 1.5 m_{violet}.

$m_1\lambda_1 = m_2\lambda_2$

$m_{red} = m_{violet}\left(\frac{4}{6}\right)$

A12. You have a choice of two converging lenses, Lens 1 has a focal length of 10.0 cm and Lens 2 has a focal length of 7.50 cm. Which one of the following scenarios will produce the largest possible focussed image on the retina when one of the lenses is used as a simple magnifier?

E

(A) Use Lens 1 and put the object to be viewed at 25 cm from your eye.
(B) Use Lens 2 and put the object to be viewed at 25 cm from your eye.
(C) Use Lens 1 and adjust the object position so that your eye is relaxed.
(D) Use Lens 2 and adjust the object position so that your eye is relaxed.
(E) Use Lens 2 and adjust the object position so that the image forms at 25 cm from your eye.

A13. A wall made of wood 4.00 cm thick has an area of 48.0 m². If the temperature inside is 25°C and the temperature outside is 14°C, at what rate is thermal energy transported through the wall by conduction? The thermal conductivity of wood is 0.080 J/s·m·°C.

D

(A) 82 W (B) 210 W (C) 690 W (D) 1100 W (E) 2100 W

$P = kA\frac{\Delta T}{L} = (0.080\ \text{J/s·m·°C})(48.0\ \text{m}^2)\left(\frac{25°\text{C} - 14°\text{C}}{0.0400\ \text{m}}\right) = 1100\ \text{J/s}$

A14. Two samples, A and B, of the same ideal gas have the same pressure and density. Sample B has twice the volume of sample A. How does the rms speed of the molecules in sample B compare to the rms speed of the molecules in sample A?

C

(A) $v_{rms,B} = \frac{1}{4} v_{rms,A}$ (B) $v_{rms,B} = \frac{1}{2} v_{rms,A}$ (C) $v_{rms,B} = v_{rms,A}$
(D) $v_{rms,B} = 2 v_{rms,A}$ (E) $v_{rms,B} = 4 v_{rms,A}$

$PV = nRT = Nk_BT$

$P = \frac{N}{V}k_BT = \rho_N k_BT$ → $\frac{P}{\rho_N k_B} = T$ ⇒ same temperature

$\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$ ⇒ same v_{rms}

(same gas ⇒ same mass)

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A15. In a calorimetry experiment, three samples A, B, and C, with $T_A > T_B > T_C$ are placed in thermal contact. When the samples have reached thermal equilibrium at a common temperature T, which one of the following statements *must* be true? (Recall that Q is positive if energy is transferred as heat **to** a sample and Q is negative if energy is transferred as heat **from** a sample.)

C

(A) $T > T_B$ (B) $T < T_B$ (C) $T_A > T > T_C$
(D) $Q_A > Q_B > Q_C$ (E) $Q_A < 0$, $Q_B < 0$, and $Q_C > 0$

Don't know anything about T_B compared to T.

A16. Consider an object that is at a steady temperature of 20.0°C. By how much would you have to raise the temperature of the object for it to radiate thermal energy at twice the rate that it is emitting at 20.0°C?

B

(A) 75.5°C (B) 55.5°C (C) 40.0°C (D) 20.0°C (E) 349°C

$P = \sigma e A T^4$ $\frac{P_2}{P_1} = 2 = \frac{T_2^4}{T_1^4} = \frac{T_2^4}{(293.15K)^4} \Rightarrow T_2 = 349K = 75.5°C \Rightarrow \Delta T = 55.5°C$

A17. A particular metal does not eject electrons when it is illuminated with violet light. Which one of the following types of light may possibly eject electrons from this metal?

E

(A) infrared (B) red (C) yellow (D) green (E) ultraviolet

need higher energy (shorter λ) photons

A18. Which one of the following statements is true regarding a radioactive isotope ${}^A_Z X$ that decays by emitting a gamma ray?

B

(A) The resulting isotope has the same A value and a different Z value.
(B) The resulting isotope has the same A value and the same Z value.
(C) The resulting isotope has a different A value and the same Z value.
(D) Both A and Z are different in the resulting isotope.
(E) The isotope undergoes a transition to a state of higher energy.

A19. The atomic mass of Helium-4 is 4.00 u and the atomic mass of Sulphur-32 is 32.0 u. If the radius of the Helium-4 nucleus is R, which one of the following is the best estimate for the radius of the Sulphur-32 nucleus?

B

(A) 8 R (B) 2 R (C) 4 R (D) 2.83 R (E) 32 R

$V \propto A \propto R^3$ $R_2 = R_1 \sqrt[3]{\frac{A_2}{A_1}} = R_1 \sqrt[3]{\frac{32}{4}} = 2R_1$

A20. Which one of the following is the correct expression for the binding energy of a nucleus, ${}^A_Z X$, that has an atomic mass of M_{atomic}? m_p is the mass of a proton, m_n is the mass of a neutron, and m_H is the atomic mass of hydrogen.

E

(A) $BE = (Zm_p + Am_n)c^2$ (B) $BE = (Zm_p + (A-Z)m_n)c^2$
(C) $BE = (Zm_p + (A-Z)m_n - M_{atomic})c^2$ (D) $BE = (Zm_H + Am_n - M_{atomic})c^2$
(E) $BE = (Zm_H + (A-Z)m_n - M_{atomic})c^2$

<u>PART B</u>

Work out the answers to the following Part B questions.

Before scratching any options, be sure to double-check your logic and calculations.

You may find it advantageous to do as many of the parts of a question as you can before scratching any options.

When you have an answer that is one of the options and are confident that your method is correct, scratch that option on the scratch card. if you reveal a star on the scratch card then your answer is correct (full marks, 2/2).

If you do not reveal a star with your first scratch, try to find the error in your solution. If you reveal a star with your second scratch, you receive 1.2 marks out of 2.

Revealing the star with your third, fourth, or fifth scratches does not earn you any marks, but it does give you the correct answer.

You may answer all six Part B question groupings (B21-24, B25-28, B29-32, B33-36, B37-40, and B41-44) and you will receive the marks for your best 5 groupings.

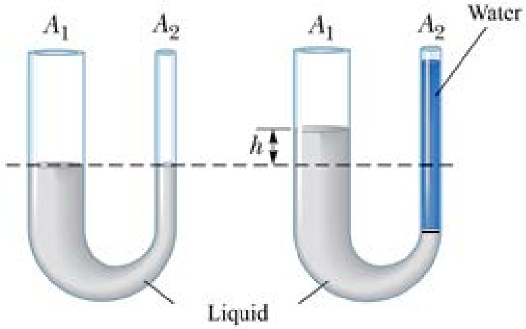
Use the provided exam booklet for your rough work.

Grouping B21 to B24:

B21. Consider two vertical cylinders of height h: cylinder 1 of radius R and cylinder 2 of radius $2R$. The same liquid is poured into each cylinder until they are full. Let P_1 be the gauge pressure at the bottom of cylinder 1 and P_2 be the gauge pressure at the bottom of cylinder 2. Which one of the following statements is correct?

(A) $P_2 = \frac{1}{4} P_1$ (B) $P_2 = P_1$ (C) $P_2 = \frac{1}{2} P_1$ (D) $P_2 = 4P_1$ (E) $P_2 = 2P_1$

An unknown liquid is poured into a U-tube as shown in the figure below. The left arm of the tube has cross sectional area A_1 of 20.0 cm^2, and the right arm has a cross-sectional area A_2 of 10.0 cm^2. 0.200 kg of water is then poured into the right arm as shown. The liquid rises in the left arm by a distance h = 2.15 cm. The density of water is 1.00×10^3 kg/m^3.



B22. Calculate the height of the water column in the right arm of the U-tube.

(A) 20.0 m (B) 0.200 cm (C) 5.00 cm (D) 20.0 cm (E) 10.0 cm

$$M_w = \rho_w V_w = \rho_w A_2 h_w \quad \Rightarrow \quad h_w = \frac{M_w}{\rho_w A_2} = 0.200 \text{ m} = 20.0 \text{ cm}$$

B23. Calculate the pressure at the boundary between the water and the unknown liquid in the right arm. Express your answer to 4 decimal places.

(A) 1.0326×10^5 Pa (B) 1.0130×10^5 Pa (C) 1.9600×10^3 Pa
(D) 9.9340×10^4 Pa (E) 1.0196×10^5 Pa

$$P = P_0 + \rho_w g h_w = 1.013\times10^5 \text{ Pa} + (1000 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(0.200 \text{ m})$$
$$P = 1.0326\times10^5 \text{ Pa}$$

B24. Calculate the density of the unknown liquid.

(A) 1.63×10^5 kg/m^3 (B) 9.30×10^3 kg/m^3
(C) 4.65×10^3 kg/m^3 (D) 3.10×10^3 kg/m^3
(E) 3.04×10^4 kg/m^3

Note that the volume of water below the dashed line is the same as the volume of unknown liquid above the dashed line. Therefore the height of water below the dashed line can be calculated:

$$V_u = V_w \quad \Rightarrow \quad A_1 h = A_2 h_{w2} \quad \Rightarrow \quad h_{w2} = \frac{A_1 h}{A_2} = 2h$$

Therefore, the height of unknown liquid in the left arm that is above the level of the water-unknown liquid boundary in the right arm is $3h$. Using the principle of "at the same level in the same liquid the pressure is the same":

$$P_{left} = P_{right}$$

$$P_0 + \rho_u g h_u = P_{right}$$

$$\rho_u g h_u = P_{right} - P_0$$

$$\rho_u = \frac{P_{right} - P_0}{g h_u} = \frac{1.0326\times10^5 \text{ Pa} - 1.013\times10^5 \text{ Pa}}{(9.80 \text{ m/s}^2)(3\times0.0215 \text{ m})} = 3.10\times10^3 \,\text{kg/m}^3$$

Grouping B25 to B28:

For a particular pipe in a pipe-organ, it has been determined that the frequencies 168 Hz and 210 Hz are two consecutive natural resonant frequencies. Use 343 m/s as the speed of sound in air.

B25. Calculate the fundamental frequency for this pipe.

(A) 84 Hz (B) 21 Hz (C) 56 Hz (D) 42 Hz (E) 63 Hz

If the pipe is open at both ends, then it resonates at frequencies of f_1, $2f_1$, $3f_1$, … where f_1 is the fundamental frequency. Therefore, the difference between two consecutive resonant frequencies is the fundamental. In this case, the fundamental frequency would be 210 Hz – 168 Hz = 42 Hz.

If the pipe is closed at one end, then it resonates at frequencies of f_1, $3f_1$, $5f_1$, … Therefore, the difference between two consecutive resonant frequencies is twice the fundamental frequency. In this case the fundamental frequency would be $2f_1$ = 42 Hz, so f_1 = 21 Hz. However, this would mean that 168 Hz is the fourth harmonic, and a pipe closed at one end only resonates at the odd harmonics.

Therefore, the pipe is open at both ends and the fundamental frequency is 42 Hz.

B26. Which one of the following statements correctly describes the pipe?

(A) It is closed at one end and the frequency of the second harmonic is 126 Hz.
(B) It is closed at one end and the frequency of the third harmonic frequency at 126 Hz.
(C) It is closed at one end and the frequency of the third harmonic is 84 Hz.
(D) It is open at both ends and the frequency of the second harmonic is 84 Hz.
(E) It is open at both ends and the frequency of the second harmonic is 112 Hz.

As noted in the answer to B25, the pipe is open at both ends. The second harmonic is 2×42 Hz = 84 Hz.

B27. Calculate the length of the pipe.

(A) 2.04 m (B) 0.122 m (C) 0.245 m (D) 8.16 m (E) 4.08 m

The open ends of the pipe are displacement antinodes (the air is free to move). The simplest standing wave pattern that satisfies these boundary conditions is antinodes at each end, node in the middle. This corresponds to the length of the pipe being equal to half of the wavelength.

$$L = \tfrac{1}{2}\lambda = \tfrac{1}{2}\frac{\upsilon}{f} = \tfrac{1}{2}\frac{343\text{ m/s}}{42\text{ Hz}} = 4.08\text{ m}$$

B28. The pipe is now made to resonate at the frequency of the third harmonic. Another pipe nearby is made to resonate at its fundamental frequency and a beat frequency of 2.00 Hz is heard. Which one of the following is a possible description for the second pipe?

(A) It is open at both ends and its length is 0.67 m.
(B) It is open at both ends and its length is 0.69 m.
(C) It is closed at one end and its length is 1.34 m.
(D) It is closed at one end and its length is 1.38 m.
(E) It is closed at one end and its length is 0.69 m.

The first pipe is resonating at a frequency of 3 × 42 Hz = 126 Hz. Therefore, the fundamental frequency of the second pipe is either 124 Hz or 128 Hz, since $f_{beat} = f_1 - f_2$.

If the second pipe is open at both ends:

$$L = \tfrac{1}{2}\lambda = \tfrac{1}{2}\frac{\upsilon}{f} = \tfrac{1}{2}\frac{343\text{ m/s}}{124\text{ Hz}} = 1.38\text{ m or } L = \tfrac{1}{2}\lambda = \tfrac{1}{2}\frac{\upsilon}{f} = \tfrac{1}{2}\frac{343\text{ m/s}}{128\text{ Hz}} = 1.34\text{ m}$$

If the second pipe is closed at one end, then the length of the pipe corresponds to ¼ of the fundamental wavelength, because there must be a node at the closed end and an antinode at the open end:

$$L = \tfrac{1}{4}\lambda = \tfrac{1}{4}\frac{\upsilon}{f} = \tfrac{1}{4}\frac{343\text{ m/s}}{124\text{ Hz}} = 0.69\text{ m or } L = \tfrac{1}{4}\lambda = \tfrac{1}{4}\frac{\upsilon}{f} = \tfrac{1}{4}\frac{343\text{ m/s}}{128\text{ Hz}} = 0.67\text{ m}$$

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Grouping B29 to B32:

The lens in a slide projector has a focal length of 102 mm and the slide is located 108 mm from the lens. A clear, focussed image appears on a screen placed some distance away from the lens.

B29. Which one of the following statements is correct regarding the lens and the image that it produces? Image orientation is defined relative to the object.

(A) converging lens; real and inverted image
(B) converging lens; real and upright image
(C) converging lens; virtual and upright image
(D) diverging lens; real and upright image
(E) diverging lens; virtual and inverted image

Must use a converging lens to obtain an image on the screen (a real image), and real images formed by a single lens are always inverted.

B30. Calculate the distance from the lens to the screen. Express your answer to the nearest mm.

(A) 2500 mm (B) 5250 mm (C) 5447 mm (D) 1905 mm (E) 1836 mm

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f} \Rightarrow q=\left(\frac{1}{f}-\frac{1}{p}\right)^{-1}=\left(\frac{1}{102\text{ mm}}-\frac{1}{108\text{ mm}}\right)^{-1}=1.836\times10^{3}\text{mm}$$

B31. The height of the slide is 33.0 mm. Determine the height of the image of the slide on the screen.

(A) 0.194 m (B) 5.61 m (C) 0.561 m (D) 1.94 m (E) 0.607 m

$$M=\frac{h_i}{h_o}=-\frac{q}{p} \Rightarrow h_i=-\frac{q}{p}h_o=-\frac{1.836\text{ m}}{0.108\text{ m}}(33.0\text{ mm})=-561\text{ mm}=-0.561\text{ m}$$

B32. The lens in the projector is replaced with one with a focal length of 98.0 mm. If the slide-screen distance is kept the same, determine the distance one has to move the lens in order to form a clear image on the screen.

(A) The lens must be moved 4.5 mm away from the slide.
(B) The lens must be moved 4.5 mm toward the slide.
(C) The lens must be moved 10 mm away from the slide.
(D) The lens must be moved 10 mm toward the slide.
(E) Since the slide-screen distance is unchanged, the lens does not need to be moved.

The slide-screen distance is $p + q$ = 108 mm + 1836 mm = 1944 mm = d. Therefore, the new image distance can be expressed as $q_2 = d - p_2$.

$$\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f} \quad \Rightarrow \quad \frac{1}{p_2} + \frac{1}{d - p_2} = \frac{1}{f} \quad \Rightarrow \quad \frac{d - p_2 + p_2}{p_2(d - p_2)} = \frac{1}{f} \quad \Rightarrow \quad \frac{d}{p_2(d - p_2)} = \frac{1}{f}$$

$$df = p_2 d - p_2^{\,2} \quad \Rightarrow \quad p_2^{\,2} - p_2 d + df = 0 \quad \Rightarrow \quad p_2^{\,2} - (1944\text{ mm})p_2 + (1944\text{ mm})(98.0\text{ mm}) = 0$$

$$p_2^{\,2} - (1944\text{ mm})p_2 + (190512\text{ mm}^2) = 0$$

$$p_2 = \frac{1944\text{ mm} \pm \sqrt{(-1944\text{ mm})^2 - 4(1)(190512\text{ mm}^2)}}{2} = 1840\text{ mm or }103.5\text{ mm}$$

Although both solutions are mathematically correct, only 103.5 mm makes sense physically. (You wouldn't have a slide projector that was almost 2 metres long!)

Since the slide was originally placed 108 mm from the lens, the lens would have to be moved 108 mm − 103.5 mm = 4.5 mm toward the slide to obtain a focussed image on the screen.

Grouping B33 to B36:

B33. Which one of the following statements correctly describes the process by which the human eye adjusts to maintain focus on an object that is approaching the eye?

(A) The diameter of the pupil increases.
(B) The focal length of the eye lens becomes longer.
(C) The focal length of the eye lens becomes shorter.
(D) The lens-retina distance increases.
(E) The lens-retina distance decreases.

(C) is correct.

The distance from the lens to the retina in a person's eyes is 2.00 cm.

B34. Assume that the person's eyes can form focused images of objects at distances between 28.0 cm and infinity. Calculate the upper and lower limits of the focal lengths of the person's eyes.

(A) 2.000 to 4.643 cm (B) 2.000 to 2.154 cm (C) 1.867 to 2.154 cm
(D) 1.867 to 2.000 cm (E) 4.643 cm to infinity

$$f_{\min} = \left(\frac{1}{p_{\min}} + \frac{1}{q}\right)^{-1} = \left(\frac{1}{28.0\text{ cm}} + \frac{1}{2.00\text{ cm}}\right)^{-1} = 1.867\text{ cm}$$

$$f_{\max} = \left(\frac{1}{p_{\max}} + \frac{1}{q}\right)^{-1} = \left(\frac{1}{\infty} + \frac{1}{2.00\text{ cm}}\right)^{-1} = 2.00\text{ cm}$$

B35. The person looks at an object 2.00 m tall that is a distance of 23.5 metres away. Calculate the size of the image on the person's retina.

(A) 0.851 mm (B) 1.18 mm (C) 1.70 mm (D) 5.88 mm (E) 2.35 mm

$$M = \frac{h_i}{h_o} = -\frac{q}{p} \Rightarrow h_i = \left|\left(-\frac{q}{p}\right)h_o\right| = \left|\left(-\frac{2.00\text{ cm}}{2350\text{ cm}}\right)\right|(2.00\text{ m}) = 1.70\times10^{-3}\text{ m} = 1.70\text{ mm}$$

B36. Thirty years later, the person can no longer focus on objects closer than 75.4 cm. Calculate the refractive power (in diopters) of the reading glasses that will restore the person’s ability to see objects as close as 28.0 cm from the eyes. Assume that the glasses are worn 2.00 cm from the eyes.

(A) +2.24 D (B) +2.48 D (C) +4.90 D (D) +5.21 D (E) +2.80 D

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When an object is located 28.0 cm from the person's eyes, want the reading glasses to form an image at a distance of 75.4 cm from the eyes. Therefore, for the reading glasses, p = 28.0 cm – 2.00 cm = 26.0 cm and
q = –(75.4 cm – 2.00 cm) = –73.4 cm

$$P = \frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{0.260\text{ m}} + \frac{1}{(-0.734\text{ m})} = +2.48\text{ D}$$

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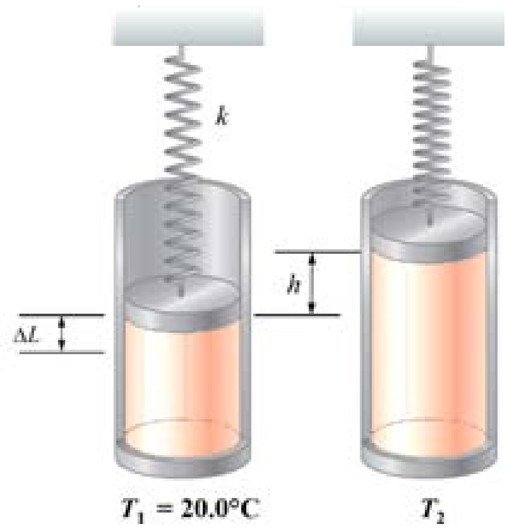
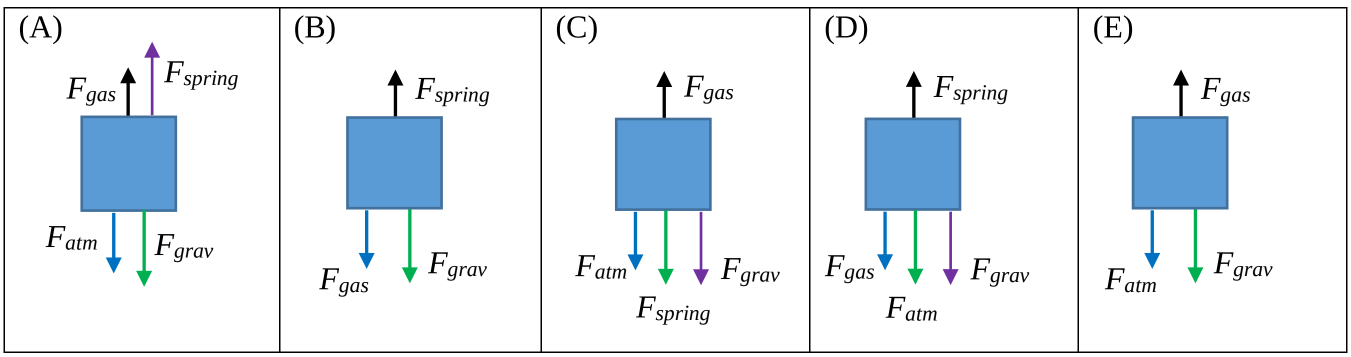
Grouping B37 to B40:

An expandable cylinder has its lid connected to a spring of force constant 2.00×10^3 N/m. The area of the bottom of the lid (the cross-sectional area of the cylinder) is $0.0100\ \text{m}^2$ and the mass of the lid is 0.600 kg. Initially, at a temperature of 20.0°C (T_1), the spring is compressed by ΔL from its equilibrium length, the volume enclosed by the cylinder is $5.00 \times 10^{-3}\ \text{m}^3$, and it contains an ideal gas at a pressure of 1.20 atm. At a higher temperature T_2, the lid rises up by h = 20.0 cm. Assume a massless spring and no gas leaks.



In the free-body diagrams below, F_{gas} is the force on the lid due to the gas in the cylinder, F_{spring} is the force on the lid due to the spring, F_{atm} is the force on the lid due to the atmosphere, and F_{grav} is the weight of the lid.

B37. Which one of the following is the correct free-body diagram for the lid at 20.0°C ?



The spring is compressed, so the spring force is downward. The force of the atmosphere on the top surface of the lid is downward, weight of the lid is downward, and the force of the gas on the bottom surface of the lid is upward. (C)

B38. Calculate the compression ΔL of the spring at 20.0°C.

(A) 2.94 cm (B) 60.6 cm (C) 6.06 cm (D) 10.1 cm (E) 9.84 cm

$$\sum F = 0 \Rightarrow +F_{gas} - F_{atm} - F_{spring} - F_{grav} = 0 \Rightarrow F_{spring} = F_{gas} - F_{atm} - F_{grav}$$

$$k\Delta L = P_{gas}A - P_{atm}A - Mg$$

$$\Delta L = \frac{(P_{gas} - P_{atm})A - Mg}{k} = \frac{(1.20\ \text{atm} - 1.00\ \text{atm})(1.013\times10^5\ \text{Pa/atm})(0.0100\ \text{m}^2) - (0.600\ \text{kg})(9.80\ \text{m/s}^2)}{2.00\times10^3\ \text{N/m}}$$

$$\Delta L = 0.0984\ \text{m} = 9.84\ \text{cm}$$

B39. Calculate the pressure of the gas at T_2.

(A) 1.41×10^5 Pa (B) 1.02×10^5 Pa (C) 1.62×10^5 Pa (D) 1.22×10^5 Pa (E) 1.36×10^5 Pa

The same free-body diagram applies to the lid, but now the spring is compressed by a distance of $\Delta L + d$.

$$\sum F = 0 \;\Rightarrow\; +F_{gas} - F_{atm} - F_{spring} - F_{grav} = 0 \;\Rightarrow\; F_{gas} = F_{spring} + F_{atm} + F_{grav}$$

$$P_{gas}A = k(\Delta L + d) + P_{atm}A + Mg$$

$$P_{gas} = \frac{k(\Delta L + d) + P_{atm}A + Mg}{A}$$

$$P_{gas} = \frac{2.00\times10^3 \text{ N/m}(0.0984 \text{ m} + 0.200 \text{ m}) + (1.013\times10^5 \text{Pa})(0.0100 \text{ m}^2) + (0.600 \text{ kg})(9.80 \text{ m/s}^2)}{0.0100 \text{ m}^2}$$

$$P_{gas} = 1.616\times10^5 \text{Pa}$$

B40. Calculate T_2.

(A) 310 K (B) 656 K (C) 272 K (D) 547 K (E) 396 K

Since there are no gas leaks, the number of moles of gas does not change. Apply the Ideal Gas Law, remembering that temperatures must be in K and pressures must be absolute.

$$PV = nRT \;\Rightarrow\; \frac{PV}{T} = nR \;\Rightarrow\; \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \;\Rightarrow\; T_2 = \frac{P_2V_2T_1}{P_1V_1}$$

Note that $V_1 = 5.00 \text{ L} \times 1000 \text{ cm}^3/\text{L} \times 1 \text{ m}^3/(100 \text{ cm})^3 = 5.00\times10^{-3}\text{m}^3$

$$T_2 = \frac{(1.62\times10^5 \text{ Pa})(V_1 + Ad)(273.15 + 20.0)\text{K}}{(1.20)(1.013\times10^5 \text{ Pa})V_1}$$

$$T_2 = \frac{(1.62\times10^5 \text{ Pa})(5.00\times10^{-3}\text{m}^3 + (0.0100 \text{ m}^2)(0.200 \text{ m}))(293.15\text{K})}{(1.20)(1.013\times10^5 \text{ Pa})(5.00\times10^{-3}\text{m}^3)} = 547 \text{ K}$$

Grouping B41 to B44:

B41. Which one of the following statements is true regarding Compton scattering?

(A) The wavelength of the scattered photon is less than the wavelength of the incident photon, and the change in wavelength depends only on the scattering angle and some constants.
(B) The wavelength of the scattered photon is greater than the wavelength of the incident photon, and the change in wavelength depends only on the scattering angle and some constants.
(C) The wavelength of the scattered photon is less than the wavelength of the incident photon, and the change in wavelength depends on the scattering angle, the wavelength of the incident photon, and some constants.
(D) The wavelength of the scattered photon is greater than the wavelength of the incident photon, and the change in wavelength depends on the scattering angle, the wavelength of the incident photon, and some constants.
(E) The wavelength of the scattered photon is less than the wavelength of the incident photon, and the change in wavelength depends only on the wavelength of the incident photon and some constants.

Some energy is transferred to the electron, so the scattered photon has less energy than the incident photon, and therefore its wavelength is greater than the wavelength of the incident photon. The change in wavelength depends only on the scattering angle and some constants (h, m_e, c). (B)

A photon, moving in the $+x$-direction, scatters off a free stationary electron. The wavelength of the incident photon is 0.0600 nm. After the collision, the electron moves at an angle α below the $+x$-axis, while the photon moves at an angle $\theta = 70.3°$ above the $+x$-axis.

B42. Calculate the energy of the scattered photon. Keep 4 significant figures in your answer.

(A) 2.013×10^4 eV (B) 2.074×10^4 eV (C) 2.041×10^4 eV
(D) 7.712×10^4 eV (E) 1.240×10^4 eV

$$\lambda = \frac{h}{m_e c}(1-\cos\theta)+\lambda_0 = \frac{6.626\times10^{-34}\text{Js}}{(9.109\times10^{-31}\text{kg})(2.998\times10^{8}\text{m/s})}(1-\cos(70.3^\circ))+0.0600\times10^{-9}\text{m}$$

$$\lambda = 0.0616\times10^{-9}\text{m} = 0.0616\text{ nm}$$

$$E = \frac{hc}{\lambda} = \frac{1240\text{ eVnm}}{0.0616\text{ nm}} = 2.013\times10^{4}\text{ eV}$$

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B43. Calculate the speed of the electron after the interaction with the incident photon.

(A) 9.75×10^{6} m/s (B) 6.89×10^{6} m/s (C) 3.44×10^{16} m/s
(D) 1.38×10^{7} m/s (E) 3.00×10^{8} m/s

Energy is conserved in the interaction, so the kinetic energy of the scattered electron equals the energy difference between the incident and scattered photons.

$$E_{i,photon} = \frac{hc}{\lambda_i} = \frac{1240\text{ eVnm}}{0.0600\text{ nm}} = 2.067\times 10^{4}\text{ eV}$$

$$KE_e = E_{i,photon} - E_{f,photon} = 2.067\times 10^{4}\text{ eV} - 2.013\times 10^{4}\text{ eV} = 540\text{ eV} = \tfrac{1}{2}m_e\upsilon^2$$

$$\upsilon = \sqrt{\frac{2KE_e}{m_e}} = \sqrt{\frac{2(540\text{ eV})\times(1.602\times 10^{-19}\text{ C/e})}{9.109\times 10^{-31}\text{ kg}}} = 1.38\times 10^{7}\text{ m/s}$$

B44. Calculate the angle α.

(A) 70.3° (B) 19.7° (C) 36.3° (D) 45.0° (E) 53.7°

$$p_{photon,i,y} + p_{electron,i,y} = p_{photon,f,y} + p_{electron,f,y}$$

$$0 + 0 = \frac{h}{\lambda}\sin\theta - m_e\upsilon\sin\alpha \quad \Rightarrow \quad m_e\upsilon\sin\alpha = \frac{h}{\lambda}\sin\theta$$

$$\sin\alpha = \frac{h}{\lambda m_e\upsilon}\sin\theta \quad \Rightarrow \quad \alpha = \text{ invsin}\left(\frac{h}{\lambda m_e\upsilon}\sin\theta\right)$$

$$\alpha = \text{ invsin}\left(\frac{6.626\times 10^{-34}\text{Js}}{(0.0616\times 10^{-9}\text{m})(9.109\times 10^{-31}\text{kg})(1.38\times 10^{7}\text{ m/s})}\sin(70.3^\circ)\right) = 53.7^\circ$$

END OF EXAMINATION