

# Physics 157 Midterm 1 Review Package - **Solutions**

UBC Engineering Undergraduate Society

Attempt questions to the best of your ability. Problems are ranked in difficulty as (\*) for easy, (\*\*) for medium, and (\*\*\*) for difficult. Difficulty is subjective, so do not be discouraged if you are stuck on a (\*) problem.

Solutions will be posted at: <https://ubcengineers.ca/review-packages>

If you believe that there is an error in these solutions, or have any questions, comments, or suggestions regarding EUS Tutoring sessions, please e-mail us at: [tutoring@ubcengineers.ca](mailto:tutoring@ubcengineers.ca). If you are interested in helping with EUS tutoring sessions in the future or other academic events run by the EUS, please e-mail [vpacademic@ubcengineers.ca](mailto:vpacademic@ubcengineers.ca).

Want a warm up? These are the easier problems <a href="#">1, 2, 3, 4</a>	Short on study time? These cover most of the material <a href="#">6, 9, 11, 12, 15</a>	Want a challenge? These are some tougher questions <a href="#">14, 15, 16</a>
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Some of the problems in this package were not created by the EUS. Those problems originated from one of the following sources:

- Fundamentals of Physics / David Halliday, Robert Resnick, Jearl Walker. – 9th ed.
- Exercises for the Feynman Lectures on Physics / Matthew Sands, Richard Feynman, Robert Leighton.

All solutions prepared by the EUS.

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## EUS Health and Wellness Study Tips

- **Eat Healthy**—Your body needs fuel to get through all of your long hours studying. You should eat a variety of food (not just a variety of ramen) and get all of your food groups in.
- **Take Breaks**—Your brain needs a chance to rest: take a fifteen minute study break every couple of hours. Staring at the same physics problem until your eyes go numb wont help you understand the material.
- **Sleep**—Weve all been told we need 8 hours of sleep a night, university shouldnt change this. Get to know how much sleep you need and set up a regular sleep schedule.

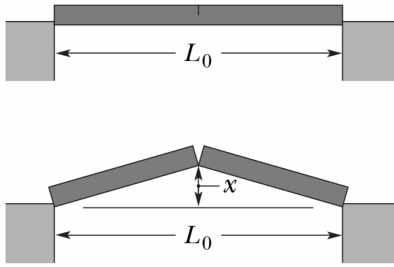


Good Luck!

- (\*) 1. A cylindrical aluminum rod, with an initial length of 0.8000 m and a radius of  $1000.0 \mu\text{m}$ , is clamped in place at one end and then stretched by a machine pulling parallel to its length at its other end. Assume that the rod's mass density does not change and that its radius decreases uniformly along the length of the rod. Find the magnitude of the force required to decrease the radius to  $999.9 \mu\text{m}$ . The Young's modulus for aluminum is  $Y_{Al} = 70 \text{ GPa}$ .

- (\*) 2. A cylinder with a leak-less, frictionless piston contains  $1.0 \text{ m}^3$  of a monatomic gas with a gauge pressure of 1 atm. The gas is very slowly compressed until the final volume is only  $0.4 \text{ m}^3$ . How much work  $W$  must be done to accomplish this compression?

- (\*) 3. Due to a temperature rise of  $32^\circ\text{C}$ , a bar with a crack at its centre buckles upward. If the fixed distance  $L_0$  is 3.77 m and the coefficient of linear expansion of the bar is  $25 \cdot 10^{-6}/^\circ\text{C}$ , find the rise  $x$  of the centre.

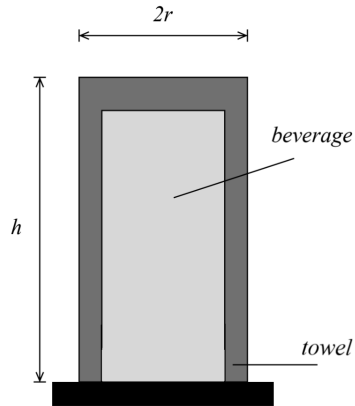


- (\*) 4. The temperature of a Pyrex disk is changed from  $10.0^\circ\text{C}$  to  $60.0^\circ\text{C}$ . Its initial radius is  $8.00\text{ cm}$ , and its initial thickness is  $0.50\text{ cm}$ . Young's Modulus of pyrex is  $67\text{ GPa}$ , and the linear thermal expansion coefficient of Pyrex is  $3.2 \cdot 10^{-6}/^\circ\text{C}$ .
- (a) What is the change in volume of the disk?
  - (b) If the disk is constrained rigidly across its faces before it is heated, what will be the stress in the disk after it is heated?

- (\*) 5. The giant hornet *Vespa mandarinia japonica* preys on Japanese bees. However, if a hornet attempts to invade a beehive, several hundred of the bees quickly form a compact ball around the hornet to stop it. They overheat the hornet by quickly raising their body temperatures from the normal  $35^\circ\text{C}$  to  $47^\circ\text{C}$ , which is lethal to the hornet but not to the bees. Assume the following: 500 bees form a ball of radius  $R = 2.0\text{ cm}$  for a time  $t = 20\text{ min}$ , the primary loss of energy by the ball is by thermal radiation, the ball's surface has emissivity  $\epsilon = 0.80$ , and the ball has uniform temperature. On average, how much additional energy must each bee produce during the 20 minutes to maintain  $47^\circ\text{C}$ ?

- (\*\*) 6. Suppose that when Pluto is at its average distance of 39.5 AU from the Sun, it has an average temperature of  $-235^\circ\text{C}$ . Compute the albedo  $\alpha_p$  of Pluto. Note that 1 AU = 1 Astronomical Unit = distance from Sun to Earth. The solar constant at Earth is  $1367\text{ W/m}^2$ .

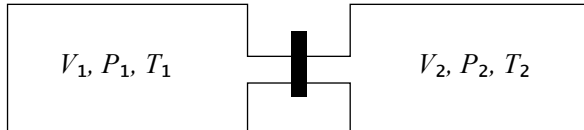
- (\*\*) 7. On a hot day, a cold beverage can is placed on an insulating surface and covered with a wet towel, such that there is no heat exchange between the surface and the bottom of the can. Assume that the only energy exchanges taking place are evaporation and radiation through the top and side surfaces. The towel and beverage have temperature  $T = 15^\circ\text{C}$ , the environment has temperature  $T_{env} = 32^\circ\text{C}$ , and the towel/beverage package is a cylinder with radius  $r = 2.2\text{ cm}$  and height  $h = 10\text{ cm}$ . Approximate the emissivity as  $\epsilon = 1$ , and neglect other energy changes. At what rate  $\Delta m/\Delta t$  is the container losing water mass? The latent heat of vaporization of water is  $L = 2260\text{ J/g}$ .





- (\*\*) 8. Two containers of equal volume,  $V_1 = V_2 = V$ , are connected by a small tube with a valve, as shown. Initially, the valve is closed and the two volumes contain a monatomic gas at pressures  $P_1$  and  $P_2$  and temperatures  $T_1$  and  $T_2$ , respectively. After the valve is opened, what will be
- (a) the final pressure  $P_f$  and
  - (b) the final temperature  $T_f$  inside the joint volume?

Neglect heat lost from the system. Express your answers in terms of  $P_1$ ,  $P_2$ ,  $T_1$ ,  $T_2$ .



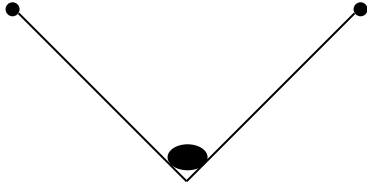
(\*\*) 9. Two 50 g ice cubes are dropped into 200 g of water in a thermally insulated container. The water is initially at  $25^\circ\text{C}$ , and the ice comes directly from a freezer at  $-15^\circ\text{C}$ .

(a) What is the final temperature of the mixture at thermal equilibrium?

(b) What is the final temperature if only one ice cube is used?

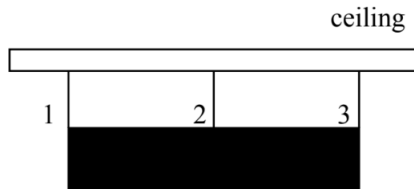
The latent heat of fusion of water is  $L_w = 336 \text{ J/g}$ . The specific heat capacity of water is  $c_w = 4186 \text{ J/kg}^\circ\text{C}$ . The specific heat capacity of ice is  $c_i = 2030 \text{ J/kg}^\circ\text{C}$ .

- (\*\*) 10. An insect is caught at the midpoint of a spider-web thread. The thread breaks under a stress of  $8.2 \cdot 10^8 \text{ N/m}^2$ , and a strain of 2.00. Initially, it was horizontal and had a length of 2.00 cm and a cross-sectional area of  $8.00 \cdot 10^{-12} \text{ m}^2$ . Assume that as the thread is stretched, its volume remains constant, and its cross-sectional area decreases uniformly along the thread. If the weight of the insect puts the thread on the verge of breaking, what is the insect's mass?



- (\*\*) 11. Shown below is a 300 kg cylinder that is horizontal. Three steel wires support the cylinder from a ceiling. Wires 1 and 3 are attached at the ends of the cylinder, and wire 2 is attached at the centre. Initially, (before the cylinder was put in place) wires 1 and 3 were 2.000 m long and wire 2 was 6 mm longer than that. Now, (with the cylinder in place) all three wires have been stretched to a cross sectional area of  $2.00 \cdot 10^{-6} \text{ m}^2$ . Young's Modulus for steel is  $Y = 200 \cdot 10^9 \text{ N/m}^2$ . What is the tension in,

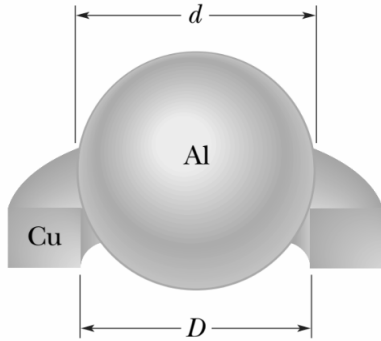
- (a) wire 1?  
(b) wire 2?



- (\*\*) 12. A 50 litre tank is connected to a 15 litre tank through a short tube containing a pressure release valve that will only allow gas to pass from the larger tank to the smaller tank if the pressure in the larger tank exceeds the pressure in the smaller tank by  $117,300\text{Pa}$ . If at  $17^\circ\text{C}$  the larger tank contains gas at atmospheric pressure and the smaller tank is evacuated, what will be the pressure  $P$  in the smaller tank when both tanks are at  $162^\circ\text{C}$ ?

- (\*\*) 13. A 20.0 g copper ring at  $0.0^\circ\text{C}$  has an inner diameter of  $D = 2.54000$  cm. An aluminum sphere at  $100.0^\circ\text{C}$  has a diameter of  $d = 2.54508$  cm. The sphere is put on top of the ring, and the two are allowed to come to thermal equilibrium, with no heat lost to the surroundings. The sphere just passes through the ring at the equilibrium temperature. What is the mass of the sphere?

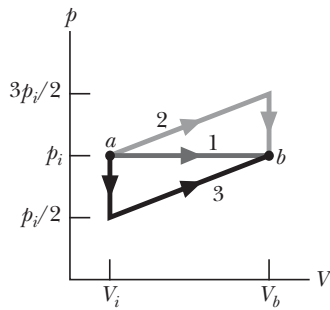
The coefficient of volume expansion of aluminum is  $\beta_{\text{Al}} = 7.2 \cdot 10^{-5}/^\circ\text{C}$ , and the coefficient of volume expansion of copper is  $\beta_{\text{Cu}} = 5.1 \cdot 10^{-5}/^\circ\text{C}$ . The specific heat capacity of aluminum is  $c_{\text{Al}} = 910 \text{ J/kg}^\circ\text{C}$ , and the specific heat capacity of copper is  $c_{\text{Cu}} = 390 \text{ J/kg}^\circ\text{C}$ .



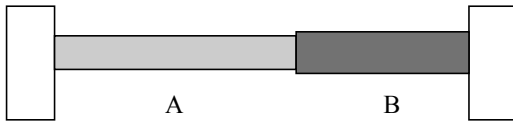
- (\*\*\*) 14. A sample of gas undergoes a transition from an initial state  $a$  to a final state  $b$  by three different paths, as shown in the  $P$ - $V$  diagram, where  $V_b = 5.00V_i$ . The energy transferred to the gas as heat in process 1 is  $10P_iV_i$ .

- How many degrees of freedom does the sample of gas have?
- Find the energy transferred to the gas as heat in process 2.
- Find the change in internal energy that the gas undergoes in process 3.

Express your answers in terms of  $P_i$ ,  $V_i$ .

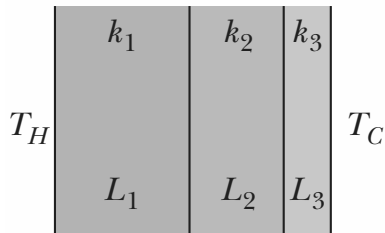


- (\*\*\*) 15. Two rods are perfectly constrained between rigid constraints, as shown. Initially, at  $15^\circ\text{C}$ , they have no stress in them. Rod A has a cross sectional area of  $40\text{ cm}^2$ , and rod B has a cross sectional area of  $50\text{ cm}^2$ . Rod A is  $30\text{ cm}$  long, and rod B is  $20\text{ cm}$  long. Rod A has Young's modulus of  $10^{10}\text{ Pa}$ , and rod B has Young's modulus of  $2 \cdot 10^9\text{ Pa}$ . Rod A has thermal expansion coefficient of  $2.4 \cdot 10^{-5}/^\circ\text{C}$ , and rod B has thermal expansion coefficient of  $5.7 \cdot 10^{-6}/^\circ\text{C}$ . If the temperature of both is raised to  $40^\circ\text{C}$ ,
- What will be the stress in rod A?
  - What will be the stress in rod B?
  - What will be the length of rod A?
  - What will be the length of rod B?





- (\*\*\*) 16. The figure shows the cross section of a wall made of three layers. The layer thicknesses are  $L_1$ ,  $L_2 = 0.700L_1$ , and  $L_3 = 0.350L_1$ . The thermal conductivities are  $k_1$ ,  $k_2 = 0.900k_1$ , and  $k_3 = 0.800k_1$ . The temperatures at the left and right sides of the wall are  $T_H = 30.0^\circ\text{C}$  and  $T_C = -15.0^\circ\text{C}$ . Thermal conduction is steady.
- What are the temperatures at each interface? (where two layers meet)
  - If  $k_2$  were, instead, equal to  $1.1k_1$ , would the rate at which energy is conducted through the wall be greater than, less than, or the same as previously?
  - Using the  $k$  values from part (b), what would be the values of the temperatures at the two interfaces?
  - Using the  $k$  values from part (a), if the thermal conductivity of layer 1 is  $k_1 = 50 \text{ W/m} \cdot \text{K}$ , and the thickness of layer 1 is  $L_1 = 60 \text{ cm}$ , what are the  $R$  values of each of the walls?



**Useful Constants and Conversion Ratios:**

$$R = \text{Ideal Gas constant} = 8.31451 \text{ J/molK}, \quad 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa}, \quad 1 \text{ atm} \cdot \text{litre} = 101.3 \text{ J}$$

$$\sigma = \text{Stefan-Boltzmann constant} = 5.6704 \times 10^{-8} \text{ W/m}^2\text{K}^4, \quad \gamma_{\text{air}} = 1.4, \quad C_{V_{\text{air}}} = 20.8 \text{ J/molK}$$

$$\rho_{\text{water}} = \text{Density of water} = 1 \text{ gram/cm}^3 = 1000 \text{ kg/m}^3$$

**Mechanics:**

$$\text{Linear Motion: } x = x_0 + \frac{1}{2}(v_0 + v)t, \quad x = x_0 + v_0t + \frac{1}{2}at^2, \quad v = v_0 + at, \quad v^2 = v_0^2 + 2a(x - x_0)$$

$$\text{Circular Motion: } a_c = \frac{v^2}{r}$$

$$\text{Forces: } \mathbf{F} = m\mathbf{a} = \frac{d}{dt}\mathbf{p}, \quad \text{Friction: } |\mathbf{F}| = \mu|\mathbf{N}|, \quad \text{Spring: } \mathbf{F} = -k\mathbf{x}, \quad \text{Damping: } \mathbf{F} = -b\mathbf{v}$$

$$\text{Buoyant } |\mathbf{F}| = \rho V g$$

$$W = \text{Work} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{r} = \mathbf{F} \cdot \Delta\mathbf{r}, \quad K = \frac{1}{2}mv^2, \quad \Delta U_{\text{gravity}} = mg\Delta h, \quad \Delta U_{\text{spring}} = \frac{1}{2}kx^2$$

$$P = \frac{dW}{dt} = \mathbf{F} \cdot \mathbf{v}$$

**Thermodynamics:**

$$\text{Thermal Expansion: } \Delta L = \alpha L_0 \Delta T, \quad \text{Stress and Strain: } \frac{|\mathbf{F}|}{A} = Y \frac{\Delta L}{L}, \quad \text{Ideal Gas Law: } PV = nRT$$

$$K_{\text{av}} = \frac{3}{2}kT$$

$$\text{Thermal Conductivity: } I = \frac{\Delta Q}{\Delta t} = kA \frac{\Delta T}{\Delta x}$$

$$\text{Black Body Radiation: } P = e\sigma A(T_B^4 - T_S^4), \quad \lambda_{\text{max}}T = 2.8977685 \times 10^{-3} \text{ m} \cdot \text{K}$$

$$\text{Solar Irradiation: } P = (1 - \alpha)S_c r^2 \pi$$

$$\text{Internal Energy: } U = nC_V T$$

$$\text{First Law of Thermodynamics: } dQ = dU + dW \text{ For an ideal gas, } dW = PdV$$

$$\text{Work for an } i\text{sothermal process } W = nRT \ln(V_f/V_i)$$

$$\text{Work for an } a\text{diabatic expansion } TV^{\gamma-1} = \text{constant, if the number of moles is constant } PV^\gamma = C$$

where  $C$  is a constant and  $\gamma = C_P/C_V$

$$\text{Work for adiabatic process: } W = \int_{V_1}^{V_2} PdV = C \int_{V_1}^{V_2} \frac{dV}{V^\gamma} = \frac{C}{1-\gamma} (V_2^{1-\gamma} - V_1^{1-\gamma})$$

$$\text{Heat Transfer: } Q = mc\Delta T, \quad Q = mL, \quad C_P = C_V + R, \quad C_V = \frac{f}{2}R, \text{ where } f = \text{degrees of freedom.}$$

$$f = 3 \text{ for monatomic and } f = 5 \text{ for diatomic.}$$

$$dS = \frac{dQ}{T}$$

$$e = W/Q_H, \quad COP_{\text{Cooling}} = \frac{|Q_C|}{|W|}, \quad COP_{\text{Heating}} = \frac{|Q_H|}{|W|}, \quad e_{\text{Carnot}} = 1 - \frac{T_C}{T_H}$$

**Integrals:**

$$\int x^n dx = \frac{x^{n+1}}{n+1} + C, n \neq -1 \quad \int x^{-1} dx = \ln x + C$$

**Trigonometry:**

$$\sin \theta_1 + \sin \theta_2 = 2 \cos \left( \frac{\theta_1 - \theta_2}{2} \right) \sin \left( \frac{\theta_1 + \theta_2}{2} \right)$$

**Area and Volume:**

$$\text{Surface Area of a sphere: } A = 4\pi r^2. \text{ Lateral surface area of a cylinder: } A = 2\pi r l.$$

$$\text{Area of a circle: } A = \pi r^2. \text{ Volume of a cylinder: } V = l\pi r^2 \text{ Volume of a sphere: } V = \frac{4}{3}\pi r^3$$

**Oscillations:**

$$\omega = 2\pi f, \quad T = \frac{1}{f}, \quad x = A \cos(\omega t + \phi), \quad \omega^2 = \frac{k}{m}$$

$$\text{Damped Oscillations: } x = A_0 e^{-\frac{bt}{2m}} \cos(\omega t + \phi), \text{ where } \omega = \sqrt{\omega_0^2 - \left(\frac{b}{2m}\right)^2}, \quad Q = 2\pi \frac{E}{\Delta E}$$

$$\text{Energy for damped } E = E_0 e^{-\frac{bt}{m}}$$