Physics 157 Midterm 2 Review Package

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/tutoring/`

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. 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.

Want a warm up?	Short on study time?	Want a challenge?
These are the easier problems	These cover most of the material	These are some tougher questions
1, 2, 3	4, 7, 9	10, 11, 12

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.
- A Student's Guide to Entropy / Don Lemons

All solutions prepared by the EUS.

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 constant current of 10 A flows through a resistor of 10 Ω which is kept at the constant temperature of 10°C.

(a) What is the rate of entropy change dS_R/dt of the resistor?

(b) What contribution dS_U/dt is made to the entropy change of the universe?

(∗) 2. The Solar Constant at Earth's atmosphere is $1390\,\mathrm{W/m^2}$. The radius of the Sun is $695 \cdot 10^6\,\mathrm{m}$, and the average distance between the Earth and the Sun is $150 \cdot 10^9\,\mathrm{m}$. Find

(a) The temperature of the Sun (assuming it radiates as a black-body)

(b) The equilibrium temperature of Earth

(∗∗) 3. Pluto's diameter is approximately 2000 km and it is is 40 times farther away from the Sun than the Earth. The solar constant at the Earth's atmosphere is $1390\,\mathrm{W/m^2}$. Assume emissivity is 1. The albedo of Pluto is 0.4.

(a) What is the total power absorbed by Pluto?

(b) What is the temperature of Pluto?

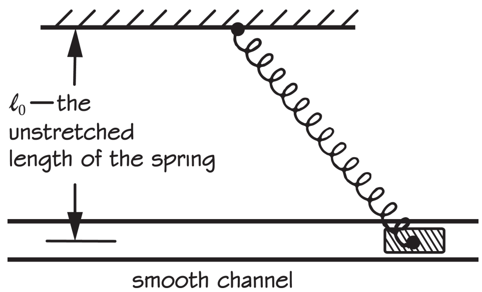
(c) Assume that the atmospheric pressure is half that of Earth's. What is the density of the molecules on Pluto's surface? (Hint: use $R = 8.2 \cdot 10^{-5}\,\mathrm{m^3 atm/k/mol}$)

(∗) 4. One mole of gas in a container is initially at a temperature 127°C. It is suddenly expanded to twice its initial volume without heat exchange with the outside. Then it is slowly compressed, holding the temperature constant, to the original volume. The final temperature is found to be $-3°$ C.

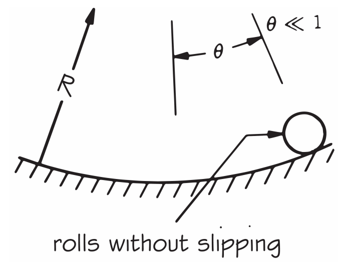
(a) What is the coefficient γ of the gas?

(b) What change ΔS in entropy, if any, has occurred?

(∗) 5. Determine which (if either) of the systems shown demonstrates simple harmonic motion. Why or why not?



(a)



(b)

(∗∗) 6. A gas of coefficient γ in a cylinder of volume V_0 at temperature T_0 and pressure P_0 is compressed slowly and adiabatically to volume $V_0/2$. After being allowed to come to temperature equilibrium (T_0) at this volume, the gas is then allowed to expand slowly and isothermally to its original volume V_0. In terms of P_0, V_0, γ, what is the net amount of work W the piston does on the gas?

(**) 7. An ideal gas with coefficient γ, is initially at the condition $P_0 = 1$ atm, $V_0 = 1$ litre, $T_0 = 300$ K. It is then:

(i) Heated at constant V until $P = 2$ atm.

(ii) Expanded at constant P until $V = 2$ litres.

(iii) Cooled at constant V until $P = 1$ atm.

(iv) Contracted at constant P until $V = 1$ litre.

(a) Draw a P–V diagram for this process.

(b) What work W is done per cycle?

(c) What is the maximum temperature T_{max} the gas attains?

(d) What is the total heat input ΔQ in steps (i) and (ii) in terms of γ?

(∗∗) 8. The first Earth settlers on the moon will have great problems in keeping their living quarters at a comfortable temperature. Consider the use of Carnot engines for climate control. Assume that the temperature during the moon-day is 100°C, and during the moon-night is $-100°$ C The temperature of the living quarters is to be kept at 20°C. The heat conduction rate through the walls of the living quarters is 0.5 kW per degree of temperature difference.

(a) Find the power P_{day} which has to be supplied to the Carnot engine during the day, and

(b) the power P_{night} which must be supplied at night.

(∗∗) 9. Two samples of gas, A and B of the same initial volume V_0, and at the same initial absolute pressure P_0, are suddenly compressed adiabatically, each to one half its initial volume.

(a) Express the final pressures (P_A, P_B) of each sample in terms of the initial pressure P_0, if $\gamma_A = 5/3$ (monatomic) and $\gamma_B = 7/5$ (diatomic)

(b) Find the ratio of work W_A/W_B required to perform the two compressions described.

(∗∗) 10. Two particles A and B execute harmonic motion of the same amplitude (10 cm) on the same straight line. For particle A, $\omega_A = 20$ rad/s; for B, $\omega_B = 21$ rad/s. If at $t = 0$, they both pass through $x = 0$ in the positive x-direction (hence both of them are "in phase")

(a) How far apart, Δx will they be at $t = 0.350$ s?

(b) What is the velocity V of B relative to A at $t = 0.350$ s?

(c) How long after $t = 0$ does it take for them to *both* be at $x = 0$ at the same time again?

(∗∗) 11. A 20 g hook with a 5 g weight on it is attached to a vertical spring of negligible mass. When the spring is displaced from equilibrium the system is found to oscillate in vertical simple harmonic motion with a period of $\pi/3$ s. If the 5 g weight is replaced by a 25 g weight, how far z can the spring be displaced from equilibrium before release, if the weight is not to jump off the hook?

(∗ ∗ ∗) 12. In an ideal reversible engine employing 28 g nitrogen as working substance ($\gamma = 7/5$) in a cyclic operation $a \to b \to c \to d$ without valves, the temperature of the source is 400 K, and the temperature of of the sink is 300 K. The initial volume of gas at point a is 6.0 litres and the volume at point c is 18.0 litres.

(a) At what volume V_b should the cylinder be changed from heat input (isothermal expansion) to isolation and adiabatic expansion (from V_b to V_c)?

(b) At what volume V_d should the adiabatic compression begin?

(c) How much heat $\Delta Q_{a\to b}$ is put in during the $V_a \to V_b$ part of the cycle?

(d) How much heat $\Delta Q_{c\to d}$ is extracted during the $V_c \to V_d$ part?

(e) What is the efficiency e of the engine?

(f) What change ΔS in entropy per gram occurs in the working substance during $a \to b$ and $c \to d$?

Hint. *For a Carnot cycle the expansion ratios V_b/V_a and V_c/V_d are equal. Draw yourself a P–V diagram to help understand the cycle.*

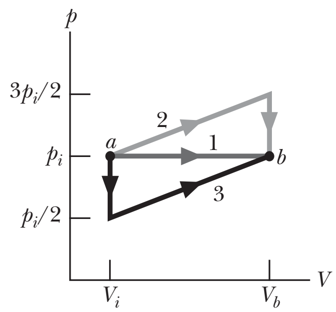
(∗∗∗) 13. A sample of gas undergoes a transition from an initial state a to a final state b by three different paths, as shown in the P-V diagram, where $V_b = 5.00V_i$. The energy transferred to the gas as heat in process 1 is $10P_iV_i$.

(a) How many degrees of freedom does the sample of gas have?

(b) Find the energy transferred to the gas as heat in process 2.

(c) Find the change in internal energy that the gas undergoes in process 3.

Express your answers in terms of P_i, V_i.



(∗∗∗) 14. An insulated container with a movable, frictionless piston of mass M and area A, contains N grams of helium gas in a volume V_1, as shown. The external pressure is P. The gas is *very slowly* heated by an internal heating coil until the volume occupied by the gas is $2V_1$. What is,

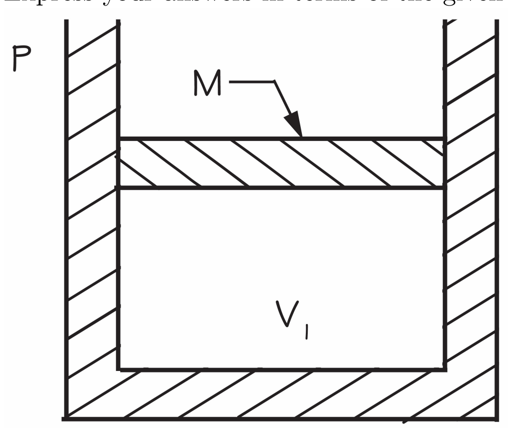
(a) the work W done by the gas?

(b) the heat ΔQ supplied to the gas?

(c) the change ΔU in the internal energy of the gas?

(d) the initial temperature T_i and the final temperature T_f of the gas?

Express your answers in terms of the given variables M, A, P, N, V_1.

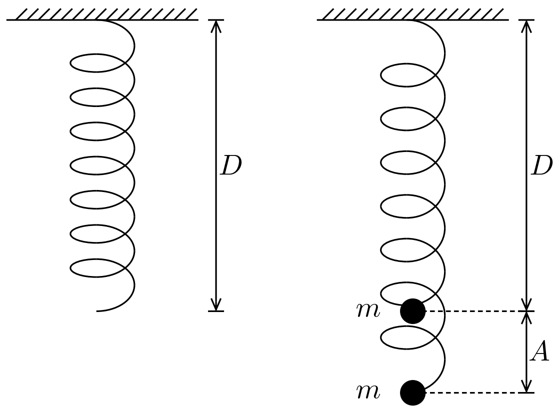


(∗ ∗ ∗) 15. A certain linear spring has a free length D. When a mass m is hung on the end, it has a length $D + A$. While it is hanging motionless with mass m attached, a second mass m is dropped from a height A onto the first one, with which it collides inelastically (i.e. they stick together). For the resulting motion, find the:

(a) period T

(b) amplitude a, and

(c) maximum height H (above the original equilibrium position)



Useful Constants and Conversion Ratios:
R = Ideal Gas constant = $8.31451\,\text{J/molK}$, $1\text{ atm} = 1.013 \times 10^5\,\text{Pa}$, $1\text{ atm} \cdot \text{litre} = 101.3\,\text{J}$
σ = Stefan-Boltzmann constant = $5.6704 \times 10^{-8}\,\text{W/m}^2\text{K}^4$, $\gamma_{\text{air}} = 1.4$, $C_{V_{\text{air}}} = 20.8\,\text{J/molK}$
ρ_{water} = Density of water = $1\,\text{gram/cm}^3 = 1000\,\text{kg/m}^3$
Mechanics:
Linear Motion: $x = x_0 + \frac{1}{2}(v_0 + v)t$, $x = x_0 + v_0 t + \frac{1}{2}at^2$, $v = v_0 + at$, $v^2 = v_0^2 + 2a(x - x_0)$
Circular Motion: $a_c = \dfrac{v^2}{r}$
Forces: $\mathbf{F} = m\mathbf{a} = \dfrac{d}{dt}\mathbf{p}$, Friction: $|\mathbf{F}| = \mu|\mathbf{N}|$, Spring: $\mathbf{F} = -k\mathbf{x}$, Damping: $\mathbf{F} = -b\mathbf{v}$
Buoyant $|\mathbf{F}| = \rho V g$
$W = \text{Work} = \displaystyle\int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{r} = \mathbf{F} \cdot \Delta\mathbf{r}$, $K = \frac{1}{2}mv^2$, $\Delta U_{\text{gravity}} = mg\Delta h$, $\Delta U_{\text{spring}} = \frac{1}{2}kx^2$
$P = \dfrac{dW}{dt} = \mathbf{F} \cdot \mathbf{v}$
Thermodynamics:
Thermal Expansion: $\Delta L = \alpha L_0 \Delta T$, Stress and Strain: $\dfrac{|\mathbf{F}|}{A} = Y\dfrac{\Delta L}{L}$, Ideal Gas Law: $PV = nRT$
$K_{\text{av}} = \frac{3}{2}kT$
Thermal Conductivity: $I = \dfrac{\Delta Q}{\Delta t} = kA\dfrac{\Delta T}{\Delta x}$
Black Body Radiation: $P = e\sigma AT^4$, $\lambda_{\max}T = 2.8977685 \times 10^{-3} m \cdot K$
Internal Energy: $U = nC_V T$
First Law of Thermodynamics: $dQ = dU + dW$ For an ideal gas, $dW = PdV$
Work for an *isothermal process* $W = nRT\ln(V_f/V_i)$
Work for an *adiabatic expansion* $TV^{\gamma-1}$ = constant, if the number of moles is constant $PV^\gamma = C$ where C is a constant and $\gamma = C_P/C_V$
Work for adiabatic process: $W = \displaystyle\int_{V_1}^{V_2} PdV = C\int_{V_1}^{V_2} \frac{dV}{V^\gamma} = \frac{C}{1-\gamma}(V_2^{1-\gamma} - V_1^{1-\gamma})$
Heat Transfer: $Q = mc\Delta T$, $Q = mL$, $C_P = C_V + R$, $C_V = \dfrac{f}{2}R$, where f = degrees of freedom.
$f = 3$ for monatomic and $f = 5$ for diatomic.
$dS = \dfrac{dQ}{T}$
$e = W/Q_H$, $COP_{\text{Cooling}} = \dfrac{|Q_C|}{|W|}$, $COP_{\text{Heating}} = \dfrac{|Q_H|}{|W|}$, $e_{\text{Carnot}} = 1 - \dfrac{T_C}{T_H}$
Integrals:
$\displaystyle\int x^n dx = \frac{x^{n+1}}{n+1} + C, n \neq 1$ $\displaystyle\int x^{-1}dx = \ln x + C$
Trigonometry:
$\sin\theta_1 + \sin\theta_2 = 2\cos\left(\dfrac{\theta_1 - \theta_2}{2}\right)\sin\left(\dfrac{\theta_1 + \theta_2}{2}\right)$
Area and Volume:
Surface Area of a sphere: $A = 4\pi r^2$. Lateral surface area of a cylinder: $A = 2\pi rl$.
Area of a circle: $A = \pi r^2$. Volume of a cylinder: $V = l\pi r^2$ Volume of a sphere: $V = \frac{4}{3}\pi r^3$
Oscillations:
$\omega = 2\pi f$, $T = \dfrac{1}{f}$, $x = A\cos(\omega t + \phi)$, $\omega^2 = \dfrac{k}{m}$
Damped Oscillations: $x = A_0 e^{-\frac{bt}{2m}}\cos(\omega t + \phi)$, where $\omega = \sqrt{w_0^2 - \left(\dfrac{b}{2m}\right)^2}$, $Q = 2\pi\dfrac{E}{\Delta E}$
Energy for damped $E = E_0 e^{-\frac{bt}{m}}$

Waves:

$v = \sqrt{\frac{T}{\mu}}$, $k = \frac{2\pi}{\lambda}$, $P = \frac{1}{2}\mu\omega^2 A^2 v$, $p_o = \rho\omega v s_0$

$v = \sqrt{\frac{\gamma RT}{M}}$, $I = \frac{P_{\text{av}}}{4\pi r^2}$, $\beta = 10dB\log_{10}\left(\frac{I}{I_0}\right)$, Doppler Effect $f' = f_0\left(\frac{v \pm v_L}{v \mp v_S}\right)$

Beats: $\Delta f = f_2 - f_1$, $y = A\cos(kx \mp \omega t + \phi)$

Interference: $k\Delta x + \Delta\phi = 2\pi n$ or $\pi(2n+1)$, $n = 0, \pm1, \pm2, \pm3, \pm4, \ldots$

Standing Waves $f_m = \frac{mv}{2L}$, $m = 1, 2, 3, \ldots$, $f_m = \frac{mv}{4L}$, $m = 1, 3, 5, \ldots$

Constants:

$k = \frac{1}{4\pi\epsilon_0} \approx 9 \times 10^9\,\text{Nm}^2/\text{C}^2$, $\epsilon_0 = 8.84 \times 10^{-12}\,\text{C}^2/\text{Nm}^2$, $e = 1.6 \times 10^{-19}\,\text{C}$

$\mu_0 = 4\pi \times 10^{-7}\,\text{Tm/A}$, $c = \frac{1}{\sqrt{\epsilon_0\mu_0}} = 299,792,458\,\text{m/s}$

Point Charge:

$|\mathbf{F}| = \frac{k|q_1 q_2|}{r^2}$, $|\mathbf{E}| = \frac{k|q|}{r^2}$, $V = \frac{kq}{r} + \text{Constant}$

Electric potential and potential energy $\Delta V = V_a - V_b = \int_a^b \mathbf{E}\cdot d\mathbf{l} = -\int_b^a \mathbf{E}\cdot d\mathbf{l}$

$E_x = -\frac{dV}{dx}$, $\mathbf{E} = -\nabla V$, $\Delta U = U_a - U_b = q(V_a - V_b)$

Maxwell's Equations:

$$\int_S \mathbf{E}\cdot d\mathbf{A} = \frac{Q_{\text{enc}}}{\epsilon_0} = 4\pi k Q_{\text{enc}} \qquad \int_S \mathbf{B}\cdot d\mathbf{A} = 0$$

$$\int_C \mathbf{B}\cdot d\mathbf{l} = \mu_0\left(I_{\text{enclosed}}\right) + \epsilon_0\mu_0\frac{d\Phi_E}{dt} \qquad \int_C \mathbf{E}\cdot d\mathbf{l} = -\frac{d\Phi_B}{dt}$$

Where S is a closed surface and C is a closed curve. $\Phi_E = \int \mathbf{E}\cdot d\mathbf{A}$ and $\Phi_B = \int \mathbf{B}\cdot d\mathbf{A}$

Energy Density:

$u_E = \frac{1}{2}\epsilon_0 E^2$ and $u_B = \frac{1}{2\mu_0}B^2$ (energy per volume)

Forces:

$\mathbf{F} = q\mathbf{E} + q\mathbf{v}\times\mathbf{B}$, $\mathbf{F} = I\mathbf{L}\times\mathbf{B}$

Capacitors:

$q = CV$, $U_C = \frac{1}{2}\cdot\frac{q^2}{C}$, For parallel plate capacitor with vacuum (air): $C = \frac{\epsilon_0 A}{d}$, $C_{\text{dielectric}} = KC_{\text{vacuum}}$

Inductors:

$\mathcal{E}_L = -L\frac{dI}{dt}$, $U_L = \frac{1}{2}LI^2$, where $L = N\Phi_B/I$ and N is the number of turns.

For a solenoid $B = \mu_0 nI$ where n is the number of turns per unit length.

DC Circuits: $V_R = IR$, $P = VI$, $P = I^2R$

(For RC circuits)$q = ae^{-t/\tau} + b, \tau = RC,$ a and b are constants

(For LR circuits)$I = ae^{-t/\tau} + b, \tau = L/R,$ a and b are constants

AC circuits: $X_L = \omega L$, $X_C = 1/(\omega C)$, $V_C = X_C I$, $V_L = X_L I$

$V = ZI$, $Z = \sqrt{(X_L - X_C)^2 + R^2}$, $P_{\text{average}} = I_{\text{rms}}^2 R$, $I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}}$

If $V = V_0\cos(\omega t)$, then $I = I_{\text{max}}\cos(\omega t - \phi)$, where $\tan\phi = \frac{X_L - X_C}{R}$, $P_{\text{av}} = V_{\text{rms}}I_{\text{rms}}\cos\phi$

Additional Equations: $d\mathbf{B} = \frac{\mu_0}{4\pi}\cdot\frac{Id\mathbf{l}\times\mathbf{r}}{r^3}$

LRC Oscillations: $q = A_0 e^{-\frac{Rt}{2L}}\cos(\omega t + \phi)$, where $\omega = \sqrt{\omega_0^2 - \left(\frac{R}{2L}\right)^2}$ and $\omega_0^2 = \frac{1}{LC}$