PHYS1112 General Physics I

Solution to Sample Questions from Previous Final Exams

1. The maximum static friction is $\mu_s mg = 0.200 \times 3.00\text{kg}\ g = 0.600\text{kg}\ g$ which is smaller than the $3.00\text{kg} \times 4.00\text{ms}^{-2} = 12.0\text{N}$ required for the box to follow the train. Hence there will be relative motion of the box and the train under kinetic friction. The acceleration is $-\frac{\mu_k mg}{m} = -\mu_k g = -0.150g = -1.47\text{ms}^{-2}$. The acceleration of the box relative to the train is hence

$$-1.47 - (-4.00) = 2.53\ \text{ms}^{-2}..$$

2. There is no friction and so the required horizontal centripetal force is provided only by the horizontal component of the normal reaction *n*:

$$n \sin 25.0° = mv^2/R$$

There is no vertical acceleration and therefore

$$n \cos 25.0° = mg$$

Hence

$$\tan 25.0° = \frac{v^2}{gR}$$

$$v = \sqrt{gR \tan 25.0°} = \sqrt{9.80 \times 500 \tan 25.0°} = 47.8\ \text{m}/s$$

3. Let the mass of the Earth be *m*.

$$\frac{mv^2}{r} = G\frac{M_s m}{r^2}$$

$$v = \sqrt{\frac{GM_s}{r}}$$

$$T = \frac{2\pi r}{v} = 2\pi r\sqrt{\frac{r}{GM_s}} = 2\pi\sqrt{\frac{r^3}{GM_s}}$$

$$M_s = \frac{4\pi^2 r^3}{GT^2}$$

4.

$$0.1\text{kg} \times v_y - 0.1\text{kg} \times 0\text{ms}^{-1} = 3\text{Ns}$$

$$0.1\text{kg} \times v_y = 3\text{Ns}$$

$$v_y = 30\text{ms}^{-1}$$

$$v = \sqrt{(30\text{ms}^{-1})^2 + (30\text{ms}^{-1})^2} = 30\sqrt{2}\text{ms}^{-1}$$

5. The angular frequency is

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{300}{3.0}} = 10\ \text{rad/s}$$

$$T = \frac{2\pi}{\omega} = 0.63\text{s}$$

The mass hits the spring which is originally at natural length. The equilibrium position of the resultant SHM should be lower than this point by $e = mg/k$. So the initial displacement from equilibrium is mg/k and the initial speed is 1.0 m/s.

$$A = \sqrt{\frac{v^2}{\omega^2} + \left(\frac{mg}{k}\right)^2} = \sqrt{\frac{1.0^2}{10^2} + \left(\frac{3.0 \times 9.8}{300}\right)^2} = 0.14\text{m}$$

6. Let the mass of the satellite and the Earth be m and M, respectively.

$$\frac{mv^2}{r} = \mathrm{G}\frac{Mm}{r^2}$$

$$v = \sqrt{\frac{GM}{r}}$$

When distance is doubled, the new speed is

$$v' = \sqrt{\frac{GM}{2r}} = \frac{v}{\sqrt{2}}$$

9. Angular frequency $\omega = \sqrt{\frac{k}{m}}$ remains the same → Period will not change.

Impulse along motion → KE increases → Total energy increases → Amplitude increases. Answer is B

10. By elimination

A. Before impact, Earth's velocity is tangential. The impact must be radial because there is no change in angular momentum. Therefore the direction of motion of Earth must be changed and there cannot be "no change" in the orbit.

B. For stable circular orbit, $v = \sqrt{\frac{GM}{r}}$, $L = mvr = m\sqrt{GMr}$ which depends on r. Larger r implies larger L. But it is given that L does not change.

C. For stable circular orbit, $v = \sqrt{\frac{GM}{r}}$, $L = mvr = m\sqrt{GMr}$ which depends on r. Smaller r implies smaller L. But it is given that L does not change.

D. $v = \sqrt{\frac{GM}{r}}$. Same orbit → same r → Same v → Same period.

E. Only E may be correct.

11. The core is denser, to become uniform, some matter need to move from the core to the outer parts. Distances increase, moment of inertia increases.

By conservation of $L = I\omega$, ω decreases. $T = 2\pi/\omega$ increases. Answer is A.

12. Slide down the plane with constant speed → Constant velocity → No net force.

Perpendicular to the plane: $n = mg \cos \alpha$.

Along the plane: $mg \sin \alpha = f = \mu_k n = \mu_k mg \cos \alpha$

$\tan \alpha = \mu_k$ → $\alpha = \tan^{-1} \mu_k = \tan^{-1} 0.15 = 8.5°$

13. Energy dissipation is maximum when the collision is completely inelastic.

Let the common final velocity be v.

By momentum conservation

$0.50 \times 1.0 + 1.0 \times (-1.0) = (0.50 + 1.0)v$

$1.5v = -0.50$

$v = -0.333$ m/s

Initial KE = $\frac{1}{2} \times 0.50 \times 1.0^2 + \frac{1}{2} \times 1.0 \times (-1.0)^2 = 0.750$ J

Final KE = $\frac{1}{2} \times 1.5 \times (-0.333)^2 = 0.0832$ J

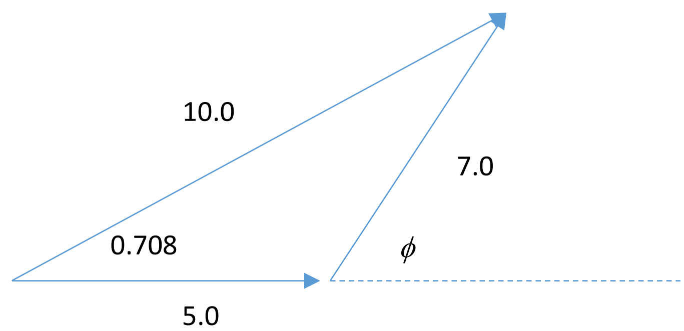
Energy dissipation = 0.750 J – 0.0832 J = 0.67 J

14. C must be wrong.

For any mass distribution spherically symmetric about the center, the gravitational force everywhere is towards the center. Therefore it is always true that the PE closer to the center is lower.

15. D is wrong. Waves transport energy, but not matter.

16. Method 1: Graphical method using phasor



$$10.0 \sin 0.708 = 7.0 \sin \phi \Rightarrow \phi = \sin^{-1} \frac{10.0 \sin 0.708}{7.0} = 1.2 \text{ rad}$$

Remark: The given lengths and angle 5.0, 7.0, 10.0, 0.708, should be consistent that they satisfy the cosine law $7.0^2 = 5.0^2 + 10.0^2 - 2(5.0)(10.0) \cos 0.708$ (Check it?). Given that, $10.0 \sin 0.708 = 7.0 \sin \phi$ and

$10.0 \cos 0.708 = 5.0 + 7.0 \cos \phi$ are equivalent (Show it?).

Method 2: Algebraic method

$$5.0 \cos(kx - \omega t) + 7.0 \cos(kx - \omega t + \phi) = 10.0 \cos(kx - \omega t + 0.708)$$

$$\begin{aligned} &5.0 \cos(kx - \omega t) + 7.0[\cos(kx - \omega t) \cos \phi - \sin(kx - \omega t) \sin \phi] \\ &\qquad = 10.0[\cos(kx - \omega t) \cos 0.708 - \sin(kx - \omega t) \sin 0.708] \end{aligned}$$

$$\begin{aligned} &(5.0 + 7.0 \cos \phi) \cos(kx - \omega t) - 7.0 \sin \phi \sin(kx - \omega t) \\ &\qquad = 10.0 \cos 0.708 \cos(kx - \omega t) - 10.0 \sin 0.708 \sin(kx - \omega t) \end{aligned}$$

$$\begin{cases} 7.0\sin\phi = 10.0\sin 0.708 \\ 5.0 + 7.0\cos\phi = 10.0\cos 0.708 \end{cases}$$

17. There are two sources, one is the sound directly from the tuning fork The other is the echo, which can be imagined as coming from the "mirror" image of the source on the other side of the wall. Let the source be moving to the right with speed 2.00 m/s away from the wall, then the image is on the left side of the wall and moving to the left with speed 2.00 m/s. The velocity of the student holding the tuning fork is 2.00 m/s to the right.

First consider the Doppler effect of the tuning fork.

$$f_L = \frac{v + v_L}{v + v_S} f_s$$

One can see that regardless of whether the student holds the tuning fork in front of him or behind him, which changes the sign of both v_L and v_S, because the two speeds are the same, we always have

$$f_L = \frac{v \pm 2.00\ \mathrm{m/s}}{v \pm 2.00\ \mathrm{m/s}} f_s = 440\ \mathrm{Hz}$$

For the echo, sign convention is direction from student to the image, i.e., to the left, is positive. Hence v_L = –2.00 m/s, v_S = +2.00 m/s.

$$f_L = \frac{340 - 2.00}{340 + 2.00} f_s = \frac{338}{342} 440 = 434.9\ \mathrm{Hz}$$

The beat frequency is 440 – 434.9= 5 Hz

18. The constant speed of the whistle is 20.0 × 0.600 = 12.0 m/s. In non-relativistic Doppler effect, velocity components perpendicular to the Source-Listener direction has no effect. So, greatest effective speed when the whistle is either moving directly towards or away from the listener, both at 12.0 m/s.

Highest frequency

$$f_L = \frac{340}{340 - 12.0} 540 = 560\ \mathrm{Hz}$$

Lowest frequency

$$f_L = \frac{340}{340 + 12.0} 540 = 522\ \mathrm{Hz}$$

19. C D are travelling waves → Wrong

Incident wave on the fixed end at $x = 0$ is $\frac{A}{2}\cos(kx+\omega t)$. Reflected wave $-\frac{A}{2}\cos(kx-\omega t)$. Resultant standing wave is

$$\frac{A}{2}\cos(kx+\omega t)-\frac{A}{2}\cos(kx-\omega t)=-A\sin(kx)\sin(\omega t)$$

Given 4 loops in 0.90m → λ = 0.90m/2 = 0.45m → $k = 2\pi/\lambda = 14\ \mathrm{m}^{-1}$.

The speed is

$$v=\sqrt{\frac{0.40g}{0.00200}}=44\ .3\ \mathrm{m/s}$$

Hence $\omega = vk$ = 620 Hz.

A: wrong k. B: wrong ω.

Correct answer is E.

Remark: $-A\sin(kx)\cos(\omega t)$ and $-A\sin(kx)\sin(\omega t)$ are the same physically. The second form can be changed to the first by choosing a different reference time which yields a phase angle of $\pi/2$, and noting that

$\sin(\omega t+\pi/2)=\cos(\omega t)$.

20. Same ω.

Three loops → 1.5λ = 0.90 m → λ = 0.60 m.

$v = \omega/k$ = 59 m/s

$m = 0.00200\ v^2/g$ = 0.7 kg

23. 78.0°C gas → 78.0°C liquid: 0.510 × 879000 = 448.3 kJ

78.0°C liquid → –114°C liquid → 0.510 × 2430 × (78.0 + 114) = 237.9 kJ

–114°C liquid → –114°C solid → 0.510 × 109000 = 55.59 kJ

Total = 742 kJ

24. Let the thickness of the ice layer be d and the depth of water be 1.4 m – d. The temperature of the water-ice boundary is 0.0°C. Equate the energy flowing away

from the boundary to the ice above and the energy flowing into the boundary from the water below:

$$0.40\frac{0.0-(-5.0)}{d} = 0.12\frac{4.0-0.0}{1.4-d} \Rightarrow d = 1.1\text{m}$$

25. The pressure depends on the average kinetic energy and the rate of collision with the piston, but is not due to collisions between particles. Under the same temperature, root-mean-square speed remains the same. However, the number density of particles increases due to decreased volume. Hence (I) is one of the factors that lead to higher pressure, but (II) (III) are not.

26.

$$\sqrt{\frac{3kT}{m}} = \sqrt{\frac{2GM}{R}}$$

$$T = \frac{2GMm}{3kR} = \frac{2\times 6.67\times 10^{-11}\times 7.35\times 10^{22}\times 3.32\times 10^{-27}}{3\times 1.38\times 10^{-23}\times 1.74\times 10^{6}} = 452\text{K} = 179℃$$

27. $(1.00\times 3R/2 + 2.00\times 5R/2)/3.00 = (13.00/6.00)\,R = 18.0$ J/mol·K

28.

$$v_{\text{rms}} = \sqrt{\frac{3kT}{m}}$$

Under the same temperature, less massive Helium molecules have higher root-mean-square speed than more massive Oxygen molecules.

29.

$$e_c = \frac{W}{Q_H} = 1 - \frac{T_c}{T_H}$$

$$\frac{20.0\text{ kJ}}{Q_H} = 1 - \frac{20.0+273.15}{800+273.15} = 0.7268$$

$$Q_H = \frac{20.0\text{ kJ}}{0.7268} = 27.5\text{ kJ}$$

30.

$$\gamma = \frac{C_P}{C_V} = \frac{nC_P \times 10.0\text{K}}{nC_V \times 10.0\text{K}} = \frac{900\ \text{kJ}}{800\ \text{kJ}} = 1.13$$

31. A. Isothermal → no change in average speed. Wrong.

B. Gas compressed → $W < 0$. Isothermal → $\Delta U = 0$. First law $Q = \Delta U + W < 0$ → Heat leaves the gas. Correct.

C. Isothermal → pV = Constant → p increases when V compressed. Wrong.

D. In theory, heat flow between two objects with the same temperature does not violate the second law of thermodynamics. If heat is somehow already flowing, it can continue to flow. In the real world, such ideal reversible processes are impossible and slight deviations from thermal equilibrium are needed to yield heat flow. In this case, during one small step of compression, work is done and the gas gets slightly hotter than water, driving a small amount of heat to flow into water, and after some time when the gas returns to the equilibrium temperature, heat flow stops. This deviation from equilibrium is small if the compression step is small. But then a large number of steps are required, and the process will be extremely slow. Under the limit that the number of steps goes to infinity, the deviations from equilibrium go to zero. Such a process is called a quasi-static process which takes infinitely long time to complete in principle. The above is what we mean by "slow". The question states that it is a slow process. Therefore it is isothermal but not adiabatic. Wrong.

E. Isothermal → $\Delta U = 0$. All work done on gas leaves the gas as heat. Wrong.

32. $pV = nRT$. Constant pressure, volume increases → T increases → Larger average KE.

33. A. Second law only forbids such process when there is no work done.

B. This can happen but requires work done.

C. Correct

D. The question doesn't state whether there is work done. Nevertheless, if there is no work done, then it is theoretically NOT possible. If there is work done, then it is possible, and it has been accomplished for a long time. So either way, the statement is wrong.

E. If the question means heat transfer with work done, then it is allowed by both first law and second law. If the question means heat transfer without work done, then it is forbidden by the second law. It can still satisfy the first law if the heat extracted from cold reservoir equals the heat dumped into the hot reservoir. So this statement is wrong.

34. It violates the second law:

$$e = \frac{80}{100} = 0.80 > e_c = 1 - \frac{10 + 273.15}{100 + 273.15} = 0.24$$

35. By first law and $\Delta U = 0$ for cyclic process.

$Q_{\text{total}} = W_{\text{total}}$

$Q_{c\to b} + Q_{b\to a} + Q_{a\to c} = W_{c\to b} + W_{b\to a} + W_{a\to c}$

$-40\text{ J} - 130\text{ J} + 400\text{ J} = 0\text{ J} - 80\text{ J} + W_{a\to c}$

$W_{a\to c} = 310\text{ J}$

36.

$$W = \int_{1.0}^{2.0} p dV = \int_{1.0}^{2.0} aV^2 dV = a\left[\frac{V^3}{3}\right]_{1.0}^{2.0} = \frac{10}{3}(2.0^3 - 1.0^3) = 23\text{ J}$$

37. $pV = nRT$

Initial: $10 \times 1.0 = nR \times 100$

Final: $(10 \times 2.0^2) \times 2.0 = nRT \rightarrow T = 800\text{ K}$

38. For adiabatic process

$$pV^\gamma = \text{Constant}$$

By ideal gas law $pV = nRT$

$$p\left(\frac{nRT}{p}\right)^\gamma = \text{Constant}$$

$$p^{1-\gamma}T^{\gamma} = \text{Constant}$$

$$1.00^{1-4/3}T^{4/3} = 5.00^{1-4/3}(5.00 + 273.15)^{4/3}$$

$$T^{4/3} = 5.00^{-1/3}278.15^{4/3}$$

$$T = 5.00^{-1/4} \times 278.15 = 186.01\text{ K} = -87°\text{C}$$

39. *a* → *b*:

$$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}nR(T_b - T_a)$$

$$W = p_a(V_b - V_a) = p_bV_b - p_aV_a = nR(T_b - T_a)$$

$$Q_{a\to b} = \Delta U + W = \frac{5}{2}nR(T_b - T_a) > 0$$

b → *c*:

$$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}nR(T_c - T_b)$$

$$W = 0$$

$$Q_{b\to c} = \Delta U + W = \frac{3}{2}nR(T_c - T_b) > 0$$

c → *d*:

$$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}nR(T_d - T_c)$$

$$W = p_c(V_d - V_c) = p_dV_d - p_cV_c = nR(T_d - T_c)$$

$$Q_{c\to d} = \Delta U + W = \frac{5}{2}nR(T_d - T_c) < 0$$

d → *a*:

$$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}nR(T_a - T_d)$$

$$W = 0$$

$$Q_{d\to a} = \Delta U + W = \frac{3}{2}nR(T_a - T_d) < 0$$

Cyclic process → $\Delta U_{\text{total}} = 0$ → $W_{\text{total}} = Q_{\text{total}}$

$$W_{\text{total}} = \frac{5}{2}nR(T_b - T_a) + \frac{3}{2}nR(T_c - T_b) + \frac{5}{2}nR(T_d - T_c) + \frac{3}{2}nR(T_a - T_d)$$
$$= nR(-T_a + T_b - T_c + T_d)$$

(Check that the same W can be obtained by the signed area of the rectangular cycle).

$$K = \frac{Q_{a\to b} + Q_{b\to c}}{-W_{\text{total}}} = \frac{\frac{5}{2}nR(T_b - T_a) + \frac{3}{2}nR(T_c - T_b)}{-nR(-T_a + T_b - T_c + T_d)} = \frac{-\frac{5}{2}T_a + T_b + \frac{3}{2}T_c}{T_a - T_b + T_c - T_d}$$

$$K = \frac{-\frac{5}{2} \times 100 + 150 + \frac{3}{2} \times 450}{100 - 150 + 450 - 300} = 5.75$$

40.

$$W_{a\to b} = p_a(V_b - V_a) = p_b V_b - p_a V_a = nR(T_b - T_a) = 2.00 \times 8.31 \times 50 = 830 \text{ J}$$

41. Take the pivot as the reference point for torque and angular momentum.

$$\Delta L = Jd = 5.00 \times 0.800 = 4.00 \text{ kg m}^2\text{s}^{-1}$$

Other external forces, viz., reaction force of the pivot, weight of the disk both yield no torque because pivot reaction acts exactly at the pivot and the line of action of weight passes through the pivot.

Hence, the angular momentum just after the action of the impulse is

$$I\omega = 4.00 \text{ kg m}^2\text{s}^{-1}$$

The moment of inertia about the pivot axis is

$$I = \frac{1}{2} \times 5.00 \times 0.500^2 + 5.00 \times 0.300^2 = 1.075 \text{ kg m}^2$$

Let the maximum angle be θ. By energy conservation

$$5.00 \times 9.80 \times 0.300(1 - \cos\theta) = \frac{1}{2}I\omega^2 = \frac{(I\omega)^2}{2I} = \frac{4.00^2}{2 \times 1.075}$$

$$\theta = 60.4°$$

42.

$$5.0 \times 10^5 V = n_A R \times 300$$

$$1.0 \times 10^5 (4V) = n_B R \times 400$$

$$\frac{f}{2} n_A R \times 300 + \frac{f}{2} n_B R \times 400 = \frac{f}{2}(n_A + n_B)RT$$

$$(n_A + n_B)RT = 300 n_A R + 400 n_B R$$

$$p(V + 4V) = (n_A + n_B)RT = 300 n_A R + 400 n_B R$$

$$p = \frac{300 n_A R + 400 n_B R}{5V} = \frac{5.0 \times 10^5 V + 1.0 \times 10^5 (4V)}{5V} = 1.8 \times 10^5 \mathrm{Pa}$$

43.

$$5.0 \times 10^5 V = n_A R \times 300$$

$$1.0 \times 10^5 (4V) = n_B R \times 400$$

$$\frac{(n_A + n_B)R}{V} = \frac{5.0 \times 10^5}{300} + \frac{4.0 \times 10^5}{400}$$

$$pV = n'_A R \times 300$$

$$p(4V) = n'_B R \times 400$$

$$\frac{(n'_A + n'_B)R}{V} = \frac{p}{300} + \frac{p}{100}$$

$$\frac{p}{300} + \frac{p}{100} = \frac{5.0 \times 10^5}{300} + \frac{4.0 \times 10^5}{400}$$

$$p = 2.0 \times 10^5 \mathrm{Pa}$$

44. To find p_c:

$$p_c \times 0.16 = 2.0R \times 820 \Rightarrow p_c = \frac{1640R}{0.16}$$

$$p_a = p_c = \frac{1640R}{0.16}$$

$$p_a \times 0.010 = 2.0RT_a \Rightarrow T_a = 51.25$$

$$Q_{a \to b} = 2.0 \times 37 \times (820 - 51.25) = 56887.5$$

$$Q_{b\to c} = W_{b\to c} = 2.0R \times 820 \ln\frac{0.16}{0.010} = 37786$$

$$W_{c\to a} = \frac{1640R}{0.16}(0.010 - 0.16) = -12777$$

$$Q_{c\to a} = 2.0 \times (37 + R)(51.25 - 820) - 1537.5R < 0$$

$$e = \frac{W_{b\to c} + W_{c\to a}}{Q_{a\to b} + Q_{b\to c}} = \frac{37786 - 12777}{56887.5 + 37786} = 0.26$$

45.

$$dU = \delta Q - \delta W = \frac{1}{2}pdV - pdV = -\frac{1}{2}pdV$$

$$d\left(\frac{f}{2}nRT\right) = -\frac{1}{2}\frac{nRT}{V}dV$$

$$\frac{dT}{T} = -\frac{1}{f}\frac{dV}{V} = -\frac{\gamma - 1}{2}\frac{dV}{V}$$

$$\ln T = -\frac{\gamma - 1}{2}\ln V + \text{Constant}$$

$$\ln\left[TV^{(\gamma-1)/2}\right] = \text{Constant}$$

$$TV^{(\gamma-1)/2} = \text{Constant}$$