Instructions:

- **Record your answers on the bubble sheet.**
- The Testing Center no longer allows students to see which problems they got right & wrong, so I strongly encourage you to **mark your answers in this test booklet**. You will get this test booklet back (but only if you **write your CID at the top of the first page**).
- You may write on this exam booklet, and are strongly encouraged to do so.
- In all problems, **ignore friction, air resistance, and the mass of all springs, pulleys, ropes, cables, strings** etc., unless specifically stated otherwise.
- Use $g = 9.8\ m/s^2$ only if there are "9.8" numbers in the answer choices; **otherwise use $g = 10\ m/s^2$.**

Problem 1. A 10 kg pendulum bob passes through the lowest part of its path at a speed of 6 m/s. What is the tension in the pendulum cable at this point if the pendulum is 2 m long?

a. Less than 235 N
b. 235 – 245
c. 245 – 255
d. 255 – 265
e. 265 – 275
f. 275 – 285
g. More than 285 N

1. FBD at lowest point: $\Sigma F = ma_c$

$T - mg = mv^2/r$

$T = mg + mv^2/r$

= 10*10 + 10*36/2 = 100 + 180 = 280 N. Choice F

Problem 2. A 3 kg mass moving east at 6 m/s on a frictionless horizontal surface collides with a 2 kg mass that is initially at rest. After the collision, the first mass moves due south at 4 m/s. What is the magnitude of the velocity of the second mass after the collision?

a. Less than 7 m/s
b. 7 – 8
c. 8 – 9
d. 9 – 10
e. 10 – 11
f. 11 – 12
g. More than 12 m/s

2. Momentum is conserved in both x- and y-directions.

x-direction	**y-direction**
$(\Sigma p_x)_{bef} = (\Sigma p_x)_{aft}$	$(\Sigma p_y)_{bef} = (\Sigma p_y)_{aft}$
$3*6 = 2*v_x$	$0 = -3*4 + 2*v_y$
$v_x = 9$	$v_y = 6$

combine components: $v = sqrt(v_x^2 + v_y^2) = sqrt(81+36) = sqrt(117)$.

Since sqrt(100) = 10 and sqrt(121) = 11, this answer is between 10 and 11. Choice E.

Problem 3. A string attached to a bucket (mass 6 kg) is wound over a large pulley having a mass of 20 kg (not zero mass!). The pulley can be considered to be a solid cylinder of radius 0.6 m. The pulley turns as the block is allowed to fall from rest. No energy is lost to friction. If the bucket falls 2 m, how fast will it be going?

a. $\sqrt{9}$ m/s
b. $\sqrt{12}$
c. $\sqrt{15}$
d. $\sqrt{18}$
e. $\sqrt{21}$

f. $\sqrt{24}$

g. $\sqrt{27}$ m/s

3. PE = KE + rotKE

mgh = ½ mv² + ½ Iω²

$$mgh = \tfrac{1}{2} mv^2 + \tfrac{1}{2} I\omega^2$$
$$= \tfrac{1}{2} mv^2 + \tfrac{1}{2} (\tfrac{1}{2} MR^2) (v^2/R^2)$$
$$= (1/2\ m + \tfrac{1}{4} M)\ v^2$$

Solve for v.

v = sqrt(mgh/(1/2 m + ¼ M)) = sqrt(6*10*2/(3+5)) = sqrt(120/8) = sqrt(15). Choice C

Problem 4. A pool is filled half with water and half with a light oil (density 400 kg/m^3). The oil floats on the water. When a diver comes up from the bottom of the pool, from the water into the oil, she will experience a buoyant force in the oil that is _____________ the buoyant force she felt in the water.

a. greater than
b. less than
c. the same as

4. $B = \rho_{fluid} * V_{object} * g$. If ρ_{fluid} is less, B is less. Choice B.

Problem 5. The figure shows a circular piece of steel with a gap. When the steel is heated, the width of the gap:

a. Increases
b. Decreases
c. Stays the same

5. Just like the hole in the washer in the class demo, the gap will increase when heated. Choice A.

Problem 6. A 50 kg ballet dancer jumps during a performance with her toes making 50 cm^2 of contact area with the floor. What is the pressure exerted by the floor over the area of contact if the dancer is jumping upwards with an acceleration of 3 m/s^2?

a. Less than 105,000 Pa
b. 105,000 – 115,000
c. 115,000 – 125,000
d. 125,000 – 135,000
e. 135,000 – 145,000
f. 145,000 – 155,000
g. More than 155,000 Pa

6. From FBD: ΣF = ma

N – mg = ma

N = m(g+a)

Also, pressure = force/area, so P = N/area. Convert area to m^2

P = m(g+a)/area = 50*(10+3)/0.005 = 50(13)(1000)/5 = 10*13*1000 = 130000. Choice D.

Problem 7. Water flows smoothly from a pipe with large diameter into a pipe with smaller diameter. The pressure of the water in the small pipe is ___________ the pressure in the large pipe.

a. greater than
b. less than
c. equal to
d. unrelated to

7. The water will flow faster in the pipe with smaller diameter (think of garden hose equation). Bernoulli's equation says that the faster water will have a lower pressure. Choice B.

Problem 8. Actual gases follow the ideal gas law to a good approximation:

a. at temperatures much higher than the boiling point
b. at temperatures close to the boiling point
c. always

8. As discussed in class (and think of the air vs helium balloon demo), the ideal gas law only holds when the molecules don't "stick together" and condense. Choice A.

Problem 9. An engine absorbs 1500 J from a hot reservoir and expels 500 J to a cold reservoir in each cycle. What is the engine's efficiency?

a. 0 – 20 %
b. 20 – 40
c. 40 – 60
d. 60 – 80
e. 80 – 100 %

9. $Q_h = |W_{net}| + Q_c \rightarrow |W_{net}| = 1500 - 500 = 1000$ J
Also, $e = |W_{net}|/Q_h \rightarrow e = 1000/1500 = 2/3 = 67\%$. Choice D.

Problem 10. Same situation. If each cycle lasts for 0.5 seconds, what is the power output of the engine?

a. Less than 500 W
b. 500 – 900
c. 900 – 1300
d. 1300 – 1700
e. 1700 – 2100
f. 2100 – 2500
g. 2500 – 2900
h. More than 2900 W

10. $P = |W_{net}|/\text{time} = 1000/0.5 = 2000$ W. Choice E.

Problem 11. You put one end of a rod in a fire and the other end in a tub of water. Which kind of rod will heat the water the fastest?

a. long and fat
b. long and thin
c. short and fat
d. short and thin

11. From the thermal conduction formula, the heat transfer will be largest if A is big and if l is small. That is "fat and short". Choice C.

Problem 12. A tank having a volume of 50 liters (0.05 m^3) contains helium gas at 2.2×10^7 Pa (about 220 atm). How many balloons can the tank blow up if each filled balloon is a sphere with volume 3 liters (0.003 m^3) and pressure 1.1×10^5 Pa (about 1.1 atm)? The tank and balloons are all at 300 K. (Don't worry about the fact that when the pressure in the tank gets below 1.1 atm, the tank won't be able to force the helium into any more balloons)

a. Less than 3300 balloons
b. 3300 – 3400
c. 3400 – 3500
d. 3500 – 3600
e. 3600 – 3700
f. 3700 – 3800
g. More than 3800 balloons.

12. The number of balloons will be #molecules in tank divided by #molecules per balloon. Or, you can use moles instead of molecules.

Ideal gas law: PV = nRT → n = PV/RT

$$\frac{n_{\text{tank}}}{n_{\text{balloon}}} = \frac{(PV/RT)_{\text{tank}}}{(PV/RT)_{\text{balloon}}} = \frac{P_{\text{tank}}V_{\text{tank}}}{P_{\text{balloon}}V_{\text{balloon}}} = \frac{220atm \times 50L}{1.1atm \times 3L} = \frac{200 \times 50}{3} = \frac{10000}{3} = 3333$$ **. Choice B.**

Problem 13. Which has more effect on the pressure that a gas exerts (keeping volume and temperature the same):

a. Doubling the number of molecules
b. Doubling the mass of each molecule
c. They have the same effect.

13. Ideal gas law: doubling the number of molecules will double the pressure. Doubling the mass, conversely, will have no effect (from a kinetic theory viewpoint, that's because the heavier molecules will travel slower and will strike the sides of the container less frequently). Choice A.

Problem 14. A "bimetallic strip" with copper on the left side and steel on the right is heated with a propane torch. Which way will the strip curve? (The expansion coefficients are given on the first page of the exam.)

a. To the left
b. To the right
c. Neither; it will stay straight

14. The copper will expand more (it has a higher α), curving the strip to the right. Choice B.

Problem 15. In the chimney effect demo, why were the puff balls sucked up the "chimney"?

a. Rising hot air from a blow torch lifted the puff balls up the chimney.
b. The wind across the top caused a pressure difference between the bottom and top of the chimney.
c. The puff balls were blown upwards by the compressed air nozzle pointed into the vertical tube.
d. The density of the puff balls was decreased, to be less than that of the surrounding air.
e. The puff balls were formed into an "airfoil" shape which generated lift.

15. Compressed air was blown across the top, causing a lower pressure via the Bernoulli effect. Choice B

Problem 16. You make a 40 kg canoe out of a rectangular form: 2.0 m long by 0.5 m wide by 0.6 m deep. Assuming it doesn't tip over, how many 1 kg lead weights can you put into the canoe before it sinks in water?

a. Fewer than 580 weights
b. 580 – 630
c. 630 – 680
d. 680 – 730
e. 730 – 780
f. 780 – 830
g. More than 830 weights

16. From FBD: $B - m_{total}g = 0$
$\rho_{fluid}V_{object}g = (40+M_{weights})g$
Cancel the g's.
1000*0.6 = 40 + Mweights
$M_{weights}$ = 600-40 = 560 kg → 560 weights. Choice A.

Problem 17. Calculate the mass flow rate (in grams per second) of blood (density = 1.0 g/cm^3) in an aorta with a cross-sectional area of 2.0 cm^2 if the flow speed is 70 cm/s.

a. Less than 85 g/s
b. 85 – 95
c. 95 – 105
d. 105 – 115

e. 115 – 125
f. 125 – 135
g. More than 135 g/s

17. VFR = A*v = 2 cm^2 * 70 cm/s = 140 cm^3/s. Convert to grams/sec by multiplying by density. 140 cm^3/s * 1 g/cm^3 = 140 g/s. Choice G.

Problem 18. A certain incandescent light bulb puts out 56.7 W of radiation power. The tungsten filament is at a temperature of 2000 K, and the surface area of the filament is 0.00025 m^3 (= $\frac{1}{4}\times10^{-3}$ m^3). What is the emissivity of the filament? (Don't worry about radiation power absorbed from the surroundings.)
a. 0 – 0.2
b. 0.2 – 0.4
c. 0.4 – 0.6
d. 0.6 – 0.8
e. 0.8 – 1

18. Radiation formula: $P = e\sigma AT^4 \rightarrow e = P/(\sigma AT^4)$

$$e = \frac{56.7}{\left(5.67\times10^{-8}\right)\left(\frac{1}{4}\times10^{-3}\right)\left(2000^4\right)} = \frac{10}{\frac{1}{4}\times10^{-11}\times2^4\times1000^4} = \frac{10}{\frac{1}{4}\times16\times10} = \frac{1}{4} = 0.25$$ **Choice B.**

Problem 19. The first law of thermodynamics is a statement of:
a. conservation of energy
b. conservation of (regular) momentum
c. conservation of angular momentum
d. conservation of mass/volume
e. none of the above

19. Choice A.

Problem 20. As an airplane flies horizontally at a constant elevation, the pressure above a wing is ____________ the pressure below the wing.
a. larger than
b. smaller than
c. the same as

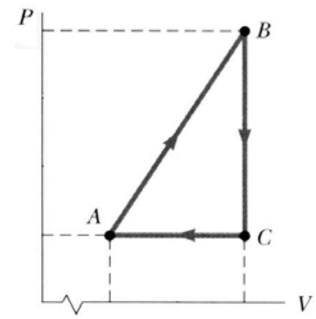
20. The lift force is due in large part from the imbalance in pressures. The pressure under the wing is greater than the pressure over the wing (because the air above the wing is traveling faster), so that there is a net upwards force from the imbalanced air pressure. Choice B.

Problem 21. A sealed room contains a mixture of helium (4 g/mole) and hydrogen (2 g/mole) gas molecules at a temperature of 50° C and a pressure of 10^6 Pa (about 10 atm). What is the ratio of the RMS speeds of the two molecules? ($v_{hydrogen}/v_{helium}$)
a. $\frac{1}{4}$
b. $\frac{1}{2}$
c. $\frac{1}{\sqrt{2}}$
d. 1
e. $\sqrt{2}$
f. 2
g. 4

21. From the kinetic theory equation: $3/2\ k_BT = ½\ mv^2 \rightarrow v = \text{sqrt}(3k_BT/m)$

$$\frac{v_{\text{hydrogen}}}{v_{\text{helium}}} = \frac{\sqrt{3k_B T / m_{\text{hydrogen}}}}{\sqrt{3k_B T / m_{\text{helium}}}} = \frac{\sqrt{1/m_{\text{hydrogen}}}}{\sqrt{1/m_{\text{helium}}}} = \sqrt{\frac{m_{\text{helium}}}{m_{\text{hydrogen}}}} = \sqrt{\frac{4}{2}} = \sqrt{2}$$ **Choice E.**

Problem 22. For the next three problems, consider the cyclic process described by the figure. For B to C: is $W_{\text{on gas}}$ positive, negative, or zero?



a. Positive
b. Negative
c. Zero

22. Volume stays constant. No work is done. Choice C.

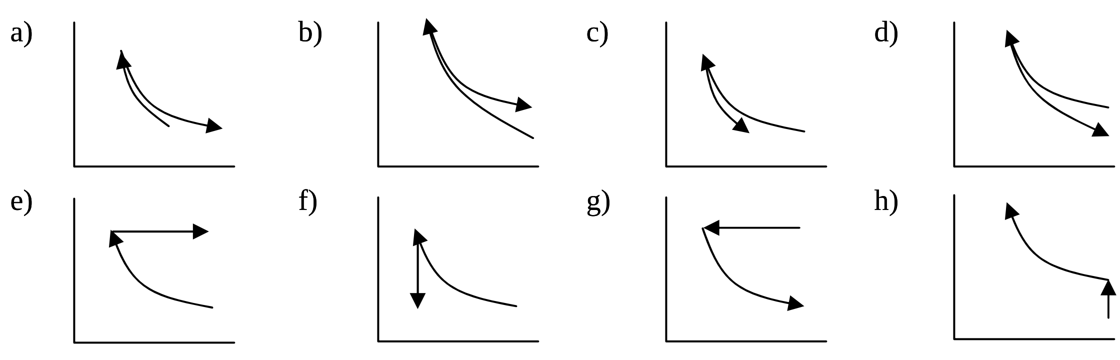
Problem 23. For A to B: does the internal energy increase, decrease, or stay the same?
a. Increase
b. Decrease
c. Stays the same ($\Delta U = 0$)

23. The path is "going up the mountain", so temperature is increasing. Therefore internal energy increases. Choice A.

Problem 24. For C to A: is heat added or taken away from the gas? (Hint: think of the 1st Law.)
a. Added
b. Taken away
c. Neither ($Q_{\text{added}} = 0$)

24. The path is "going down the mountain", so temperature is decreasing. Also, the volume is decreasing, so work is being done on the gas.
First Law: $\Delta U = Q_{\text{added}} + W_{\text{on}} \rightarrow Q_{\text{added}} = \Delta U - W_{\text{on}}$
Q_{added} = negative - (positive) = negative. Choice B.

Problem 25. The next three problems refer to this situation: First, 3 moles of a monatomic ideal gas (initial volume of 1.50 m^3, initial temperature of 350 K) are compressed to 0.50 m^3, while heat is carefully removed to cause the temperature to remain constant during the process. Next, the gas is expanded again back to its original volume, but so quickly that no heat has time to enter the gas during the process. This cools the gas to 250 K. Which of the following diagrams best represents the two processes on a standard P-V diagram?



25. The only possible ones representing an isothermal *compression* followed by an adiabatic *expansion*, are choices C and D. The problem states that the gas returns to the initial volume at the end, it must end up directly "under" the starting point. Choice D

Problem 26. Same situation. How much work (in Joules) was done on the gas in the first process?
a. $\frac{3}{2}(3)(8.31)(350)$

b. $\frac{5}{2}(3)(8.31)(350)$
c. $3(8.31)(350)$
d. $3(8.31)(350)\left(\frac{1}{0.5}-\frac{1}{1.5}\right)$
e. $3(8.31)(350)(\ln 3)$
f. $3(8.31)(350)(3)$
g. $\frac{3(8.31)(350)}{0.5}$
h. $\frac{3(8.31)(350)}{1.5}$

26. Isothermal: $|W| = |nRT \ln(V_f/V_0)|$
Since work$_{ongas}$ is positive (the gas is being compressed), I'll put V_0/V_f in the natural log. (The "area under the curve" doesn't care which is initial volume and which is final volume.)
W_{on} = 3(8.31)(350)ln(1.5/0.5) = 3(8.31)(350)ln(3). Choice E.

Problem 27. Same situation. How much work (in Joules) was done by the gas in the second process?
a. $\frac{3}{2}(3)(8.31)(100)$
b. $\frac{5}{2}(3)(8.31)(100)$
c. $3(8.31)(100)(\ln 3)$
d. $3(8.31)(250)(\ln 3)$
e. $3(8.31)(350)(\ln 3)$
f. $\frac{3(8.31)(350)}{0.5}$
g. $\frac{3(8.31)(350)}{1.5}$
h. $3(8.31)\left(\frac{1}{0.5}-\frac{1}{1.5}\right)(100)$

27. First Law: $\Delta U = Q_{added} + W_{on}$. Adiabatic: $Q_{added} = 0$
$W_{on} = \Delta U = 3/2\ nR\Delta T$
W_{by} is positive, so I'll use 350-250 for ΔT.
$W_{by} = 3/2\ nR\Delta T$ = (3/2)*(3)*8.31*100. Choice A.

Problem 28. A boat is on a lake. If an anvil (that sinks) is pushed from the boat into the water, will the overall water level of the lake rise, fall or stay the same? (compared to when the anvil was in the boat)
a. Rise
b. Fall
c. Stay the same

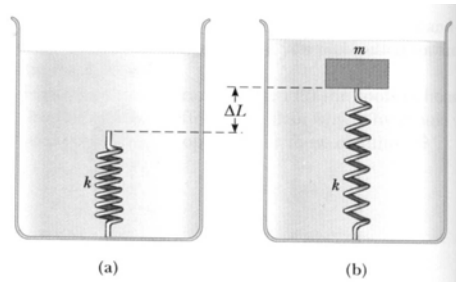
28. While in the boat, the anvil is supported by a buoyant force equal to its weight. Since $B = \rho_{fluid} * V_{oject} * g$, and $\rho_{fluid} < \rho_{anvil}$, that means it is displacing more fluid than its own volume. When it's put in the water, by contrast, it is just displacing its own volume. Therefore the overall lake level is higher when the anvil is in the boat. Choice B.

Problem 29. The second law of thermodynamics says for an engine:

a. You get more work energy out than you put in as heat
b. You get the same work energy out as you put in as heat
c. You get less work energy out than you put in as heat

29. Second Law: efficiency of an engine is always < 100%. Choice C.

Problem 30. A light spring of constant k = 100 N/m rests vertically on the bottom of a large beaker of water. A 2 kg block of wood (density = 500 kg/m^3) is connected to the spring and the mass-spring system is allowed to come to static equilibrium. What is the elongation ΔL of the spring?



a. Less than 0.11 m
b. 0.11 – 0.21
c. 0.21 – 0.31
d. 0.31 – 0.41
e. 0.41 – 0.51
f. More than 0.51 m

30. From FBD: B = mg + kx
ρ_{fluid}*V_{oject}*g = mg + kx
1000*(2/500)*10 = 2*10 + 100*x
40 = 20 + 100x
20 = 100x
x = 20/100 = 2/10 = 0.2. Choice B.

Problem 31. A 50 kg student moving at 4 m/s swings in a horizontal circle around a vertical pole, the circle having a radius of 1.6 m when measured to her center of mass. Her hands make contact with the pole over an area of 100 cm^2. How much pressure on average does the pole exert on her hands? (Hint: think of centripetal acceleration.)

a. Less than 48,000 Pa
b. 48,000 – 51,000
c. 51,000 – 54,000
d. 54,000 – 57,000
e. 57,000 – 60,000
f. 60,000 – 63,000
g. More than 63,000 Pa

31. $\Sigma F = ma_c$
$F_{pole} = mv^2/r$ = 50*16/1.6 = 50*10 = 500 N
Pressure = force/area = 500/0.01 = 50000 Pa. Choice B.
(100 cm^2 = 0.01 m^2, in case that wasn't clear)

For the next two problems: substance X is a water-like substance, except it has specific heat of 5,000 J/kg·°C in its steam-like gas phase, specific heat of 10,000 J/kg·°C in its water-like liquid phase, $L_{melting} = 3.0 \times 10^5$ J/kg, and $L_{boiling} = 1.0 \times 10^6$ J/kg. Its melting and boiling points are 0° C and 100° C, just like water.

Problem 32. An unknown mass of substance X, initially at 120° C, is added to an insulated 2 kg aluminum container initially at 20° C, and the two come to equilibrium at 60° C. How much substance X was there? (Hint: The substance X "steam" will turn into liquid during the process. The specific heat of aluminum is given on page 1.)

a. Less than 25 g
b. 25 – 35
c. 35 – 45
d. 45 – 55
e. 55 – 65
f. More than 65 g

32. $Q_{\text{gained by Al}} = Q_{\text{lost by X}}$
$(mc\Delta T)_{Al} = (mc\Delta T)_{steamX} + (mL)_{condensingX} + (mc\Delta T)_{liquidX}$
2*900*40 = m(5000*20 + 1000000 + 10000*40)
72000 = m (1500000)
m = 72000/1500000 = 72/1500 kg = 72000/1500 g = 720/15 g = 240/5 g = 48 g. Choice D.

Problem 33. A cooler has a surface area of 0.5 m^2 and a wall thickness of 4 cm. The temperature of the inner surface is 0° C, and the outside is 20° C. It takes 10 hours for 12 kg of substance X "ice" at 0°C to melt when inside the cooler. What is the thermal conductivity of the cooler's material?

a. Less than 0.15 W/m·°C
b. 0.15 – 0.25
c. 0.25 – 0.35
d. 0.35 – 0.45
e. 0.45 – 0.55
f. More than 0.55 W/m·°C

33. Q/time = kA∆T/l
mL/time = kA∆T/l
12*300000/(10*3600) = k*0.5*20/0.04

$$k = \frac{12 \times 300000 \times 0.04}{10 \times 3600 \times 0.5 \times 20} = \frac{144000}{360000} = \frac{144}{360} = \frac{48}{120} = \frac{16}{40} = \frac{8}{20} = \frac{4}{10} = 0.4$$ **Choice D.**