(Solutions)

Fall 2014
Physics 105, sections 1 and 3
Exam 3
Colton

RED

barcode here

Please write your CID__________
so that you can get your exam back

No time limit. A handwritten 3" x 5" note card is allowed. No books. Student calculators allowed. All problems equal weight.

Constants/Materials parameters:

$g = 9.8$ m/s^2
$G = 6.67 \times 10^{-11}$ N·m^2/kg^2
$k_B = 1.381 \times 10^{-23}$ J/K
$N_A = 6.022 \times 10^{23}$
$R = k_B \cdot N_A = 8.314$ J/mol·K
$\sigma = 5.67 \times 10^{-8}$ W/m^2·K^4
Mass of Sun = 1.991×10^{30} kg
Mass of Earth = 5.98×10^{24} kg

Radius of Earth = 6.38×10^6 m
Radius of Earth's orbit = 1 A.U. = 1.496×10^{11} m
Density of water: 1000 kg/m^3
Density of air (standard conditions): 1.29 kg/m^3
Linear exp. coeff. of copper: 17×10^{-6} /°C
Linear exp. coeff. of steel: 11×10^{-6} /°C
Specific heat of water: 4186 J/kg·°C
Specific heat of ice: 2090 J/kg·°C

Specific heat of steam: 2010 J/kg·°C
Specific heat of alum.: 900 J/kg·°C
Latent heat of melting (water): 3.33×10^5 J/kg
Latent heat of boiling (water): 2.26×10^6 J/kg
Thermal conduct. of alum.: 238 J/s·m·°C
$v_{sound} = 343$ m/s at 20°C

Conversion factors

1 inch = 2.54 cm
1 foot = 0.3048 m
1 mile = 1.609 km
1 mi/hr = 1 mph = 0.44704 m/s

1 lb = 4.448 N
1 m^3 = 1000 L
1 gallon = 3.785 L = 3785 cm^3
1 atm = 1.013×10^5 Pa = 14.7 psi

$T_F = \frac{9}{5}T_C + 32$
$T_K = T_C + 273.15$

Instructions:

- Write your CID at the top of the page, otherwise you may not get this exam booklet back.
- Circle your answers in this booklet if you wish to record them, but be sure to **mark your answers on the bubble sheet.** (You will not get the bubble sheet back.)
- Unless otherwise specified, **ignore air resistance** in all problems.
- Use g = 9.8 m/s^2.

Some notes on the answer ranges:

If a set of answers is given like this

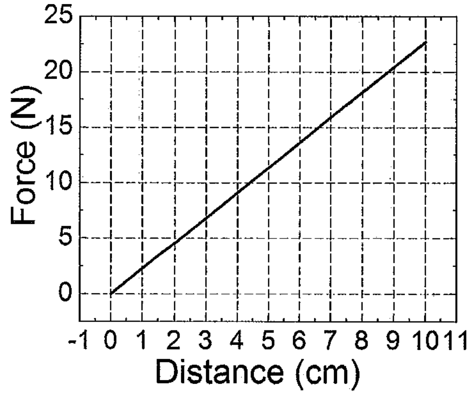
a. Less than 30 N
b. 30 – 40
c. 40 – 50
d. 50 – 60
e. More than 60 N

you can generally consider choice (a) to mean "20 – 30 N", and choice (e) to mean "60 – 70 N". I often write them like that so that if I've made a mistake when making up the answer ranges, and the answer is really less than 20 N, or larger than 70 N, then there is still an answer that is correct.

I randomize the answer choices, so the first and last choices should receive their statistical fair share of answers.

Any units and/or exponents given in the first and last answer choices also apply to the middle choices.

1. A spring is slowly stretched out, and the force required to stretch the spring is recorded at each instant. The result is shown in the graph to the right. How much work was done in stretching out the spring?



   a. Less than 0.5 J
   b. 0.5 – 0.6
   c. 0.6 – 0.7
   d. 0.7 – 0.8
   e. 0.8 – 0.9
   f. 0.9 – 1.0
   g. 1.0 – 1.1
   h. More than 1.1 J

One method:

$W = F_{ave} \cdot \Delta x$

$= \left(\frac{0+22.5N}{2}\right) \times .1m$

$= \boxed{1.125 J}$

2. A particular comet passes the Earth, a distance from the sun of 1 "A.U." (astronomical unit), traveling at a speed of 38 km/s. One month later it is half the distance to the sun, 0.5 A.U. How fast will it be traveling then? (Hint: this is a conservation of energy problem. Consider its potential energy relative to the sun.)
   a. Less than 49 km/s
   b. 49 – 51
   c. 51 – 53
   d. 53 – 55
   e. 55 – 57
   f. 57 – 59
   g. 59 – 61
   h. More than 61 km/s

aft ← bef

$E_{bef} + \cancel{W} = E_{aft}$

$(PE+KE)_{bef} = (PE+KE)_{aft}$

$-\frac{GMm}{r_0} + \frac{1}{2} m v_0^2 = -\frac{GMm}{r_f} + \frac{1}{2} m v_f^2$

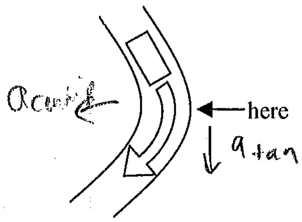
$v_f = \sqrt{v_0^2 + 2GM\left(\frac{1}{r_f} - \frac{1}{r_0}\right)}$

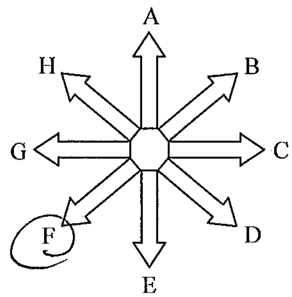
M = mass of sun
m = mass of comet

$= \sqrt{(38000 \frac{m}{s})^2 + 2(6.67 \cdot 10^{-11} \frac{Nm^2}{kg^2})(1.99 \cdot 10^{30} kg) \times \left(\frac{1}{.5 \cdot 1.496 \cdot 10^{11} m} - \frac{1}{1.496 \cdot 10^{11} m}\right)}$

$= 56740$ m/s

$\boxed{56.74 \text{ km/s}}$





3. A car goes around a corner as shown above, <u>while speeding up</u>. At the point labeled "here", in what general direction is the car's acceleration, as indicated by the arrows on the right?
   a. A
   b. B
   c. C
   d. D
   e. E
   f. F
   g. G
   h. H
   i. None; the car is not accelerating.

4. A 45 kg ballet dancer jumps during a performance, with her toes making 48 cm^2 of contact area with the floor. Her upwards acceleration as she springs is 2.5 m/s^2. How much pressure do her toes exert on the floor?

$= .0048 m^2$

   a. Less than 105 kPa
   b. 105 – 110
   c. 110 – 115
   d. 115 – 120
   e. 120 – 125
   f. 125 – 130
   g. 130 – 135
   h. More than 135 kPa

↑N
↓mg

$\Sigma F = ma$

$N - mg = ma$

$N = mg + ma$

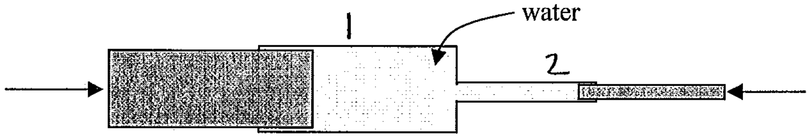
$P = \frac{force}{area} = \frac{N}{A}$

$P = \frac{m(g+a)}{A}$

$= \frac{45kg(9.8\frac{m}{s^2} + 2.5\frac{m}{s^2})}{.0048m^2}$

$= 115312.5 Pa$

$\boxed{115.31 kPa}$



5. In class we did a demo which I called a "reverse tug of war". Two people pushed on opposite horizontal hydraulic (water filled) pistons which were connected together internally. See the figure. Suppose the diameter of the left piston was 6.2 cm and the diameter of the right one was 1.4 cm. If the student on the left applied a force of 700 N, how much of a force would the student on the right have to apply in order to balance it? (i.e. neither side moves)
   - a. Less than 32 N
   - b. 32 – 33
   - c. 33 – 34
   - d. 34 – 35
   - e. 35 – 36
   - f. 36 – 37
   - g. 37 – 38
   - h. More than 38 N

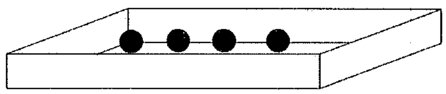
$P_1 = P_2$

$\frac{F_1}{A_1} = \frac{F_2}{A_2}$

$F_2 = F_1 \frac{A_2}{A_1}$

$F_2 = F_1 \cdot \frac{\cancel{\pi}(\frac{d_2}{2})^2}{\cancel{\pi}(\frac{d_1}{2})^2} = F_1 \left(\frac{d_2}{d_1}\right)^2$

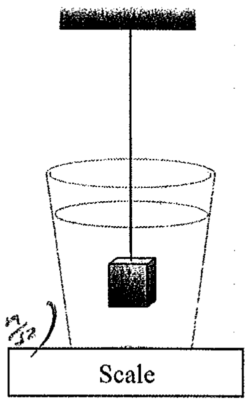
$F_2 = 700N \left(\frac{1.4\,\cancel{cm}}{6.2\,\cancel{cm}}\right)^2 = \boxed{35.69\,N}$



6. Khaavren loads cannonballs onto a raft, as shown. The raft is floating in a pond of water. What will happen to the amount of cannonballs it can support if he changes the water to oil (having a lower density)?
   - a. increase
   - b. decrease
   - c. stay the same

$B = \rho_{fl} V_{obj}\, g$

if this goes down, max B goes down



7. An open beaker of water is resting on a spring scale, with a metal block hanging from a string immersed in the water. See the figure. The hanging block is a 6 kg cube of metal, 11 cm on each edge. What will be the tension in the wire supporting the mass?
   - a. Less than 33 N
   - b. 33 – 35
   - c. 35 – 37
   - d. 37 – 39
   - e. 39 – 41
   - f. 41 – 43
   - g. 43 – 45
   - h. More than 45 N

B T mg

$\Sigma F = 0 \rightarrow T + B = mg$

$T = mg - B$

$= mg - \rho_{fl} V_{obj}\, g$

$= (6\,kg)(9.8\,\frac{m}{s^2}) - (1000\,\frac{kg}{m^3})(.11\,m)^3(9.8\,\frac{m}{s^2})$

$= \boxed{45.76\,N}$

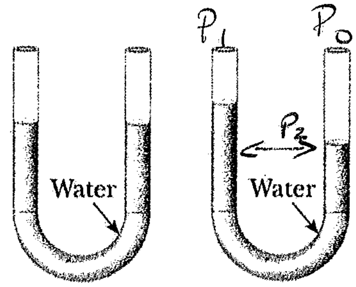
8. Water in a closed pipe (7 cm in radius) flows at a speed of 3 m/s. How long will it take for 5 m^3 of water to flow past a given point on the pipe?
   - a. Less than 85 s
   - b. 85 – 90
   - c. 90 – 95
   - d. 95 – 100
   - e. 100 – 105
   - f. 105 – 110
   - g. 110 – 115
   - h. More than 115 s

$VFR = Av$

$\frac{vol}{t} = A \cdot v$

$t = \frac{vol}{A \cdot v} = \frac{5\,m^3}{\pi(.07\,m)^2(3\,m/s)} = \boxed{108.3\,s}$

9. Bernoulli's Equation arises because of:
   - a. conservation of energy (and work done by pressure)
   - b. conservation of (regular) momentum
   - c. conservation of angular momentum
   - d. conservation of volume
   - e. equilibrium in forces and torques



10. Water is poured into a "U-Tube", open on both ends, as shown in the figure on the left. Air is then blown across the top of the left end. This causes the water to rise on the left and lower on the right, as shown in the figure on the right. If the difference between the heights on the two sides is 3.3 cm, how fast was the air going? (Densities you may need are given on page 1 of the exam.)
    a. Less than 18 m/s
    b. 18 – 20
    c. 20 – 22
    d. 22 – 24
    e. 24 – 26
    f. 26 – 28
    g. 28 – 30
    h. More than 30 m/s

$P_{2\,left} = P_{2\,right}$; use P vs. depth

$P_1 + \rho_w g h = P_0$

↑ use Bernoulli to find P_1 : $P_1 + \frac{1}{2}\rho_a v_1^2 + \cancel{\rho g h_1} = P_0 + \cancel{\frac{1}{2}\rho_a v_2^2} + \cancel{\rho g h_2}$

$P_1 = P_0 - \frac{1}{2}\rho_a v_1^2$

plug in

$(\cancel{P_0} - \frac{1}{2}\rho_a v_1^2) + \rho_w g h = \cancel{P_0}$

$\frac{1}{2}\rho_a v_1^2 = \rho_w g h \rightarrow v_1 = \sqrt{\frac{2 g h \rho_w}{\rho_a}} = \sqrt{\frac{2 \cdot 9.8\frac{m}{s^2} \cdot .033m \cdot 1000\frac{kg}{m^3}}{1.29\,kg/m^3}}$ from pg 1

$= \boxed{22.4\frac{m}{s}}$

11. The Empire State building (440 m tall) has a steel frame. If the lowest temperature for a given year in New York City was -8 °C, and the highest temperature was 40 °C, what was the change in height of the building over the year? You may assume the given height is the height for cold temperatures.
    a. Less than 12 cm
    b. 12 – 14
    c. 14 – 16
    d. 16 – 18
    e. 18 – 20
    f. 20 – 22
    g. 22 – 24
    h. More than 24 cm

$\Delta L = L_0 \alpha \Delta T$ ← from pg 1

$= (440m)(11 \cdot 10^{-6}/°C)(40°C - -8°C)$

$= .232\ m$

$\boxed{23.2\,cm}$

12. Which takes more energy: to turn 1 kg of ice at 0 °C into liquid water or to turn 1 kg of water at 100 °C into steam?
    a. ice to water
    b. water to steam
    c. same

ice to water : mL_f ↑ $3.33 \cdot 10^5\ J/kg$

water to steam : mL_v ↑ $2.26 \cdot 10^6\ J/kg$

steam is bigger!

13. Clara takes a 90 g piece of ~~aluminum~~ ice out of her freezer (at -18 °C) and adds it to 300 g of water in an insulated cup (at 30 °C). The insulated cup itself has negligible mass. How cold does the ~~aluminum~~ ice get the water?
    a. Less than 1 °C
    b. 1 – 2
    c. 2 – 3
    d. 3 – 4
    e. 4 – 5
    f. 5 – 6
    g. 6 – 7
    h. More than 7 °C

$Q_{gained\ by\ ice} = Q_{lost\ by\ water}$

$(mc\Delta T)_{ice} + (mL)_{ice} + (mc\Delta T)_{water\ that\ used\ to\ be\ ice} = (mc\Delta T)_{water}$

$m_i c_i (18°C) + m_i L_f + m_i c_w (T_f - 0) = m_w c_w (30°C - T_f)$

$m_i c_i \cdot 18 + m_i L_f + m_i c_w T_f = m_w c_w 30 - m_w c_w T_f$

$m_i c_w T_f + m_w c_w T_f = m_w c_w 30 - m_i c_i 18 - m_i L_f$

$T_f = \frac{m_w c_w \cdot 30 - m_i c_i 18 - m_i L_f}{m_i c_w + m_w c_w}$

units work out for reasons I discussed in class

$= \frac{300 \cdot 4186 \cdot 30 - 90 \cdot 2090 \cdot 18 - 90 \cdot 333000}{90 \cdot 4186 + 300 \cdot 4186}$ °C

$= \boxed{2.645°C}$

1 day = 86400 s

14. You very foolishly decide to build the walls of your new house out of solid aluminum, 8 cm thick. As a result, in the wintertime heat leaks out like a sieve. How much money does this cost you each day? The inside temp is 70° F (21.1° C), the average outside temperature is 25° F (-3.9° C), and your new house has a surface area of 230 m^2. The gas company charges you \$0.89 per "therm" (1.055×10^8 J). Ignore heat loss through the ground and through radiation & convection effects.
    a. Less than \$11,000
    b. 11,000 – 11,500
    c. 11,500 – 12,000
    d. 12,000 – 12,500
    e. 12,500 – 13,000
    f. 13,000 – 13,500
    g. 13,500 – 14,000
    h. More than \$14,000

$\frac{Q}{t} = \frac{kA\Delta T}{l}$

$Q = \frac{kA\Delta T}{l} \times t = \frac{(238 \frac{J}{s\,m\,°C})(230\ m^2)(21.1°C - -3.9°C)}{.08\ m} \times 86400\ sec$

$= 1.478 \cdot 10^{12}\ J \times \frac{\$.89}{1.055 \cdot 10^8\ J} = \boxed{\$12468}$

15. A certain incandescent light bulb puts out 40 W of radiation power. The tungsten filament is at a temperature of 2800 K, and the emissivity of the filament is 0.45. What is the surface area of the filament?
    a. Less than 2.0×10^{-5} m^2
    b. 2.0 – 2.1
    c. 2.1 – 2.2
    d. 2.2 – 2.3
    e. 2.3 – 2.4
    f. 2.4 – 2.5
    g. 2.5 – 2.6
    h. More than 2.6×10^{-5} m^2

$P = e\sigma AT^4 \rightarrow A = \frac{P}{e\sigma T^4}$

$= \frac{40\ W}{(.45)(5.67 \cdot 10^{-8} \frac{W}{m^2 K^4})(2800\ K)^4}$

$= \boxed{2.551 \cdot 10^{-5}\ m^2}$

.020 m^3

16. In my lab, I have a vacuum pump which can get my vacuum chamber to a pressure of 0.4 milliPascal. That's about 250 million times less pressure than 1 atm! The vacuum chamber has a volume of 20 L. How many gas molecules are still inside the chamber when it reaches that very low pressure? (The chamber is at 300K.)
    a. Less than 1.4×10^{15} molecules
    b. 1.4 – 1.5
    c. 1.5 – 1.6
    d. 1.6 – 1.7
    e. 1.7 – 1.8
    f. 1.8 – 1.9
    g. 1.9 – 2.0
    h. More than 2.0×10^{15} molecules

$PV = Nk_BT \rightarrow N = \frac{PV}{k_BT}$

$= \frac{(.4 \cdot 10^{-3}\ Pa)(.020\ m^3)}{(1.38 \cdot 10^{-23} \frac{J}{K})(300\ K)} = \boxed{1.932 \cdot 10^{15}}$

→ 293 K

17. Greg seals an "empty" (still has air inside) glass bottle at room temperature, 20° C. He then throws it into a campfire at 490° C. What is the final pressure in the bottle?
    a. Less than 2.3 atm
    b. 2.3 – 2.5
    c. 2.5 – 2.7
    d. 2.7 – 2.9
    e. 2.9 – 3.1
    f. 3.1 – 3.3
    g. 3.3 – 3.5
    h. More than 3.5 atm

763 K

$PV = nRT \quad n_1 = n_2 \rightarrow \frac{P_1 \cancel{V}}{\cancel{R}T_1} = \frac{P_2 \cancel{V}}{\cancel{R}T_2}$

$P_2 = P_1 \cdot \frac{T_2}{T_1}$

$= (1\ atm)\left(\frac{763\ K}{293\ K}\right) = \boxed{2.604\ atm}$

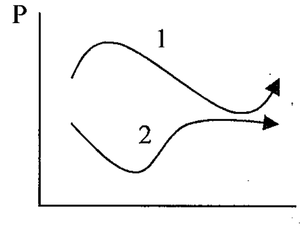
18. A cylinder contains a mixture of helium and argon gas in equilibrium at a temperature of 35 °C. Helium molecules are lighter than argon; both are monatomic. How do the average kinetic energies compare?
    a. $KE_{helium} > KE_{argon}$
    b. $KE_{helium} < KE_{argon}$
    c. $KE_{helium} = KE_{argon}$

→ $KE_{ave} = \frac{3}{2} k_BT$ for both

19. Same situation. How do the molecules' average (rms) speeds compare?
   a. $v_{helium} > v_{argon}$
   b. $v_{helium} < v_{argon}$
   c. $v_{helium} = v_{argon}$

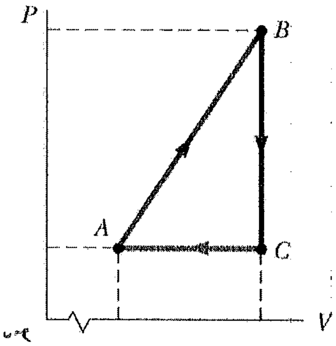
$\frac{1}{2}mv^2 = \frac{3}{2}k_BT \rightarrow v = \sqrt{\frac{3k_BT}{m}}$

lighter m has bigger v



20. Processes 1 and 2 are indicated on the PV diagram, see the figure. They both begin and end at the same volumes. In which process will the gas do more work?
   a. process 1
   b. process 2
   c. same

more area under the curve.
or equivalently, higher average P



21. A gas undergoes the cyclic processes shown on the PV diagram. For the section from A to B is $W_{on\ gas}$ positive, negative, or zero?
   a. positive
   b. negative
   c. zero

expanding $\rightarrow$ $W_{by\ gas}$ = positive
$W_{on\ gas}$ = negative

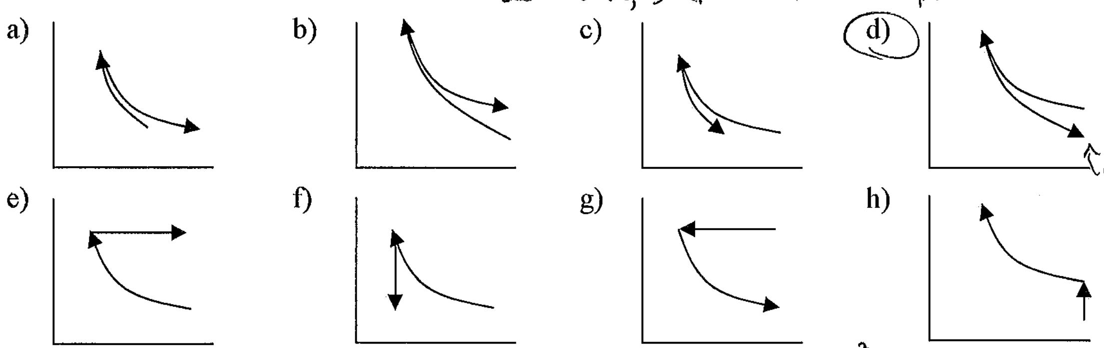
22. Same situation. For the section from B to C is $W_{on\ gas}$ positive, negative, or zero?
   a. positive
   b. negative
   c. zero

no volume change $\rightarrow$ no work

isothermal, along a temperature contour

23. Choose the PV diagram which best represents this situation: First, a gas is compressed 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.

adiabatic, steeper than the temperature contour



ends at same volume it starts out at

24. A gas is compressed at a constant pressure of 0.3 atm from a volume of 7.5 L to 3.3 L. In the process, 410 J of heat energy flows out of the gas. What is the change in the gas's internal energy? The answer will be negative; the answer choices below refer to magnitudes (absolute values) of the answer. Note: this particular gas does not fit either our monatomic or diatomic models.

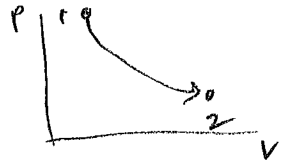
.0075 m^3 .0033 m^3

   a. Less than 210 J in magnitude
   b. 210 – 230
   c. 230 – 250
   d. 250 – 270
   e. 270 – 290
   f. 290 – 310
   g. 310 – 330
   h. More than 330 J in magnitude

$\Delta U = Q_{added} - W_{by}$
$= Q_{added} + (-P\Delta V)$
$= -410\text{J} + \left(-.3\text{atm} \cdot 1.01 \times 10^5 \frac{\text{Pa}}{\text{atm}}\right)(.0033 - .0075)\ \text{m}^3$
$= \boxed{-282.7\text{J}}$

$\to PV = nRT \to V = \frac{nRT}{P}$

25. A gas (1.3 moles) expands isothermally at a temperature of 350 K. The high and low pressures during the process were 4.0×10^5 Pa and 1.5×10^5 Pa. How much heat was added to the gas?
    a. Less than 3600 J
    b. 3600 – 3700
    c. 3700 – 3800
    d. 3800 – 3900
    e. 3900 – 4000
    f. 4000 – 4100
    g. 4100 – 4200
    h. More than 4200 J



$\cancel{\Delta U} = Q + W_{on} \to Q = -W_{on}$

$Q = W_{by}$

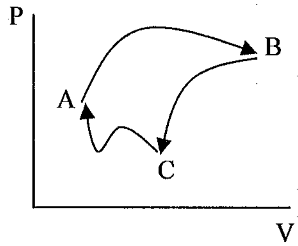
$Q = nRT \ln(V_f/V_o)$ ← work by gas, eqn given in class

$= (1.3\,\text{moles})(8.31\,\frac{J}{mol\,K})(350K) \ln\left(\frac{nRT/P_f}{nRT/P_o}\right) \to \ln(P_o/P_f)$

$= 1.3 \cdot 8.31 \cdot 350 \cdot \ln\left(\frac{4 \cdot 10^5}{1.5 \cdot 10^5}\right)$ J

$= \boxed{3709 J}$

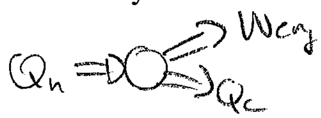
26. A heat engine undergoes a thermodynamic cycle as shown in the figure, going from state A to state B to state C, then back to state A. What is true about the internal energy of state A initially, compared to the internal energy of state A the next time around?
    a. $U_{A,first} > U_{A,next}$
    b. $U_{A,first} < U_{A,next}$
    c. $U_{A,first} = U_{A,next}$



U just depends on T_A, which will be same

so $\Delta U = 0$

27. An engine absorbs 1900 J from a hot reservoir and expels 700 J to a cold reservoir in each cycle. What is the engine's efficiency?
    a. Less than 30%
    b. 30 – 35
    c. 35 – 40
    d. 40 – 45
    e. 45 – 50
    f. 50 – 55
    g. 55 – 60
    h. More than 60%



$\to Q_h = W_{eng} + Q_c$

$W_{eng} = Q_h - Q_c = 1900 - 700$ J

$= 1200 J$

$e = \frac{W_{eng}}{Q_h} = \frac{1200 \cancel{J}}{1900 \cancel{J}} = \boxed{63.2\%}$

28. Suppose a coal-fired power plant has a capacity of 1,900 megawatts (mega = 10^6). It burns coal at 540°C and uses that heat to increase the temperature of water, turning it into steam. The steam powers a turbine which generates electricity, then must be cooled down to turn back into water for the next cycle. It's cooled down via a nearby river that has a temperature of 20°C. What is the theoretical maximum efficiency of the cycle?
    a. Less than 35%
    b. 35 – 40
    c. 40 – 45
    d. 45 – 50
    e. 50 – 55
    f. 55 – 60
    g. 60 – 65
    h. More than 65%

813K

293K

$\to$ Carnot efficiency

$e_c = 1 - \frac{T_c}{T_h}$

$= 1 - \frac{293 \cancel{K}}{813 \cancel{K}}$

$= \boxed{63.96\%}$