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ME 3322A: Thermodynamics: Fall 2014
Homework Set # 1
Due Date: August 28, 2014

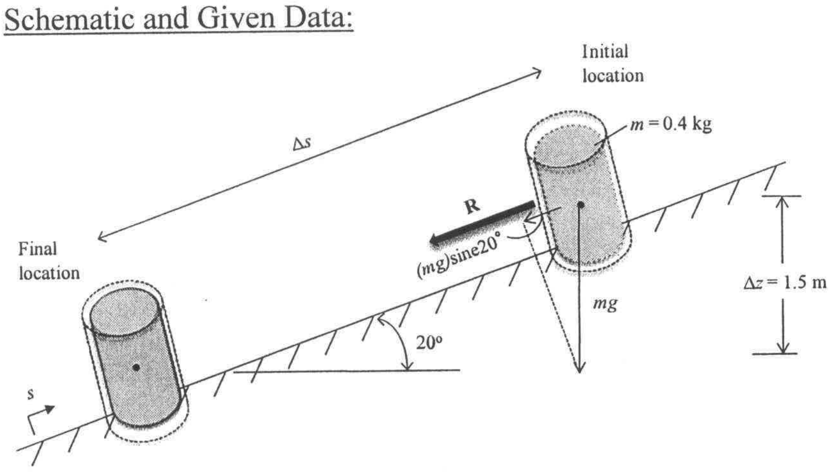
	Problem # in Textbook		Answer
	7th Ed.	**8th Ed.**	
1	2.15	2.15	6.1 J
2	2.16	2.16	11.23 m/s
3	2.29	2.30	a) 5 bars; b) 12.59 kJ
4	2.32	2.33	-400 kJ for process 3-4
5	2.36	2.37	334.2 RPM
6	2.38	2.40	

PROBLEM 2.15

Known: Can moves down a surface that is inclined relative to the horizontal. The can is acted upon by a constant force parallel to the incline and by the force of gravity.

Find: Can's change in kinetic energy, in J, and whether it is *increasing* or *decreasing*. If friction between the can and the inclined surface were significant, what effect would that have on the value of the change in kinetic energy?

Schematic and Given Data:



Engineering Model:
(1) The can is a closed system.
(2) The acceleration of gravity is constant.
(3) The applied force **R** is constant.
(4) Ignore friction between the can and inclined surface.

Analysis:

Begin with Eq. 2.6

$$\int_{s_1}^{s_2} \underline{F} \cdot d\underline{s} = \frac{1}{2} m\left(V_2^2 - V_1^2\right) = \Delta KE \qquad (1)$$

From the free body diagram in the schematic, the dot product can be expressed as

$$\underline{F} \cdot d\underline{s} = \left(\mathbf{R} + (mg)\text{sine}20^\circ\right)ds$$

Substituting into Eq. (1)

$$\int_{s_1}^{s_2} \underline{F} \cdot d\underline{s} = \int_{s_1}^{s_2} \left(\mathbf{R} + (mg)\text{sine}20^\circ\right)ds = \Delta KE \qquad (2)$$

Since $\Delta z = \Delta s$ sine 20°, Eq. (2) becomes

$$\int_{s_1}^{s_2} (\mathbf{R})ds + (mg)\Delta z = (\mathbf{R})\Delta s + (mg)\Delta z = \Delta KE \qquad (3)$$

Evaluate Δs

$$\Delta s = \frac{\Delta z}{\text{sine}\, 20^\circ} = \frac{1.5 \text{ m}}{0.342} = 4.39 \text{ m}$$

PROBLEM 2.15 (Continued)

Subsituting all known and calculated data into Eq. (3)

$$\Delta KE = (0.05N)(4.39m)\left|\frac{1J}{1N\cdot m}\right| + (0.4kg)\left(9.8\frac{m}{s^2}\right)(1.5m)\left|\frac{1N}{1\frac{kg\cdot m}{s^2}}\right|\left|\frac{1J}{1N\cdot m}\right| =$$

#1 $\Delta KE = 0.22\ J + 5.88\ J = 6.1\ J$

Which corresponds to an *increase* in kinetic energy.

If friction were significant, the magnitude of the net force acting in the direction of motion would be less, and thus the kinetic energy change would be less than calculated.

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1. Observe that in the absence of the force **R** the can is acted on only by gravity, and the can's change in kinetic energy is 5.88 J.

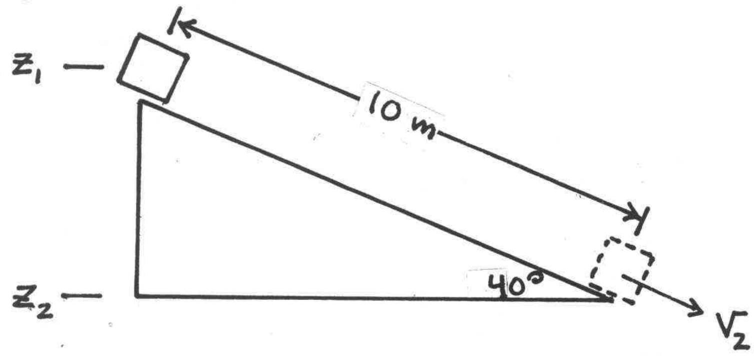
PROBLEM 2.16

KNOWN: Beginning from rest, and object of known mass slides down an inclined plane. The length of the ramp is given.

FIND: Determine the velocity of the object at the bottom of the ramp.

SCHEMATIC & GIVEN DATA:

$m = 200$ kg
$g = 9.81$ m/s^2
$V_1 = 0$



ENGR. MODEL: (1) The mass is a closed system. (2) There is no friction between the mass and the ramp, and air resistance is negligible. (3) The acceleration of gravity is constant.

ANALYSIS: By assumption (2), the only force acting on the system is the force of gravity. Thus, Eq. 2.11 applies

① $$\frac{1}{2}\cancel{m}(V_2^2 - \cancel{V_1^2}^{\,0}) + \cancel{m}g(z_2 - z_1) = 0$$

Solving for V_2

$$V_2 = \sqrt{2g(z_1 - z_2)}$$

From trigonometric relationships

$$z_1 - z_2 = (10\text{ m})\sin 40°$$

Thus

$$V_2 = \sqrt{2(9.81\text{ m/s}^2)(10\text{ m})\sin 40°}$$

$$= 11.23\text{ m/s} \longleftarrow V_2$$

1. Even though the object travels along an inclined path, the vertical distance appears in this expression.

PROBLEM 2.17

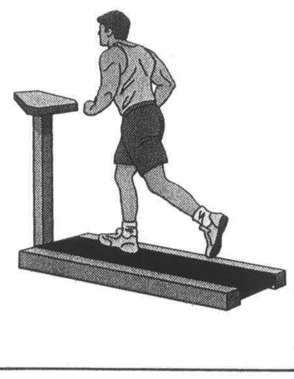


Fig. P2.17

- Exercise value = 620 kcal
- Calorie value, 1 cup of vanilla ice cream = 264 kcal (Internet)

To break even calorie-wise, Jack may have

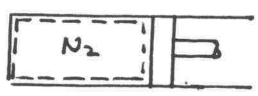
$$\frac{620\text{ kcal}}{264\text{ kcal/cup}} = 2.35\text{ cups}.$$

PROBLEM 2.28

KNOWN: N_2 gas within a piston-cylinder assembly undergoes a compression where the p-V relation is $pV^{1.35}$ = constant.

FIND: Determine the volume at the final state and the work.

SCHEMATIC & GIVEN DATA:



$pV^{1.35}$ = constant
$p_1 = 0.2\,MPa$, $V_1 = 2.75\,m^3$
$p_2 = 2\,MPa$

ENGR. MODEL:

1. The N_2 is the closed system.
2. The p-V relation during compression is specified.
3. Volume change is the only work mode.

ANALYSIS: (a) $p_1 V_1^n = p_2 V_2^n \Rightarrow V_2 = \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} V_1$, $n = 1.35$. Thus,

$$V_2 = \left(\frac{0.2\,MPa}{2\,MPa}\right)^{\frac{1}{1.35}} (2.75\,m^3) = 0.5\,m^3$$

(b) Since volume change is the work mode, Eq. 2.17 applies. Following the procedure of part (a) of Example 2.1 we have

$$W = \frac{p_2V_2 - p_1V_1}{1-n} = \frac{(2\,MPa)(0.5\,m^3) - (0.2\,MPa)(2.75\,m^3)}{1-1.35} \left|\frac{10^6\,N/m^2}{1\,MPa}\right| \left|\frac{1\,kJ}{10^3\,N\cdot m}\right|$$

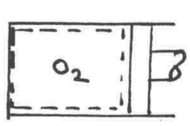
$$= -1285.7\,kJ$$

PROBLEM 2.29

KNOWN: O_2 gas within a piston-cylinder assembly undergoes an expansion where the p-V relation is $p = AV^{-1} + B$.

FIND: Determine the initial and final pressures and the work.

SCHEMATIC & GIVEN DATA:



$p = AV^{-1} + B$
$A = 0.06\,bar\cdot m^3$
$B = 3.0\,bar$
$V_1 = 0.01\,m^3$, $V_2 = 0.03\,m^3$

ENGR. MODEL:

1. The O_2 is the closed system
2. The p-V relation during expansion is specified.
3. Volume change is the only work mode.

ANALYSIS:

(a) $p_1 = [(0.06\,bar\cdot m^3)/0.01\,m^3] + 3.0\,bar$

$\therefore\ p_1 = 9.0\,bar$

$p_2 = [(0.06\,bar\cdot m^3)/(0.03\,m^3)] + 3.0\,bar$

$\therefore\ p_2 = 5.0\,bar$

(b) Since volume change is the work mode, Eq. 2.17 applies. That is,

$$W = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} \left[\frac{A}{V} + B\right] dV = A \ln\frac{V_2}{V_1} + B(V_2 - V_1)$$

$$= (0.06\,bar\cdot m^3)\ln\left(\frac{0.03\,m^3}{0.01\,m^3}\right) + (3.0\,bar)[0.03 - 0.01]\,m^3$$

$$= [0.0659 + 0.06]\,bar\cdot m^3 \left|\frac{10^5\,N/m^2}{1\,bar}\right| \left|\frac{1\,kJ}{10^3\,N\cdot m}\right|$$

$$= 12.59\,kJ$$

PROBLEM 2.31

KNOWN: Air within a piston-cylinder assembly undergoes two processes in series.

FIND: Determine the total work.

SCHEMATIC & GIVEN DATA:

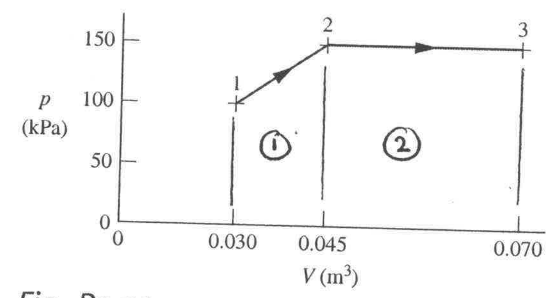


Fig. P2.32

ENGR. MODEL:

1. The air within the piston-cylinder assembly is the closed system.
2. The two-step p-V relation during expansion is specified.

ANALYSIS: Since volume change is the work mode, Eq. 2.17 applies. Furthermore the integral can be evaluated geometrically in terms of the total area under the process line:

$$W = \int_{V_1}^{V_2} p\,dV = \overset{①}{P_{ave}(V_2 - V_1)} + \overset{②}{P_2[V_3 - V_2]} = \left(\frac{P_2 + P_1}{2}\right)(V_2 - V_1) + P_2(V_3 - V_2):$$

$$= \left\{\left(\frac{150+100}{2}\right)(\text{kPa})[0.045 - 0.030]\,m^3 + (150\,\text{kPa})(0.070 - 0.045)\,m^3\right\}\left|\frac{10^3\,N/m^2}{1\,\text{kPa}}\right|\left|\frac{1\,\text{kJ}}{10^3\,N\cdot m}\right|$$

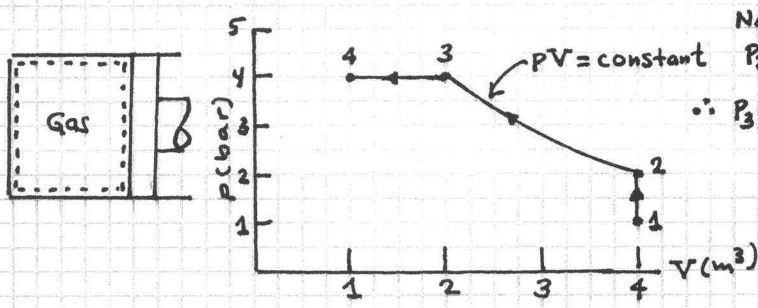
$$= 1.875\,\text{kJ} + 3.75\,\text{kJ} = 5.625\,\text{kJ}$$

PROBLEM 2.32

KNOWN: A gas contained within a piston-cylinder assembly undergoes three processes in series. State data are provided.

FIND: Sketch the processes in series on p-V coordinates and evaluate the work for each process, in kJ.

SCHEMATIC & GIVEN DATA:



Note: $P_2V_2 = P_3V_3$

$\therefore P_3 = P_2\left[\frac{V_2}{V_3}\right]$

$= 2\,\text{bar}\left[\frac{4}{2}\right]$

$= 4\,\text{bar}$

ENGINEERING MODEL:

1. The gas within the piston-cylinder is the closed system.
2. The gas experiences three processes, in series, as shown in the sketch.

ANALYSIS: The work is given by Eq. 2.17: $W = \int p\,dV$

Process 1-2: V is constant. Thus, the piston does not move, and $W_{12} = 0$.

Process 2-3: $W_{23} = \int_2^3 \frac{C}{V}\,dV = C\ln\frac{V_3}{V_2} = P_2V_2\ln\frac{V_3}{V_2}$

$$= \left(2\times10^5\frac{N}{m^2}\right)(4\,m^3)\left|\frac{1\,\text{kJ}}{10^3\,N\cdot m}\right|\ln\left[\frac{2}{4}\right] = -554.5\,\text{kJ}$$

Process 3-4: $W_{34} = p[V_4 - V_3]$

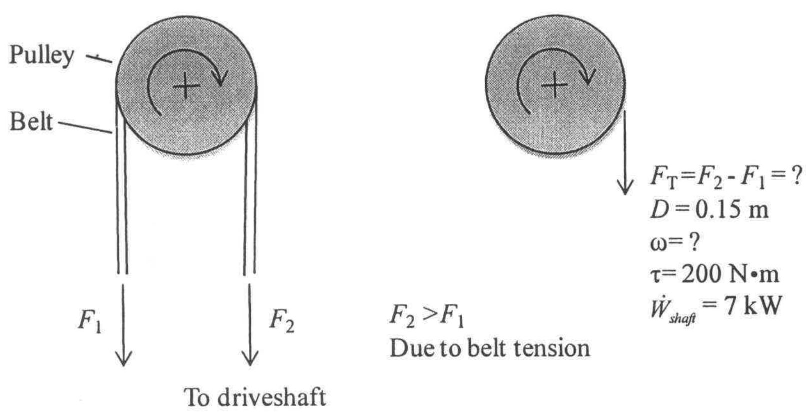
$$= \left(4\times10^5\frac{N}{m^2}\right)(1-2)\,m^3\left|\frac{1\,\text{kJ}}{10^3\,N\cdot m}\right| = -400\,\text{kJ}$$

PROBLEM 2.36

Known: Pulley turns a belt rotating the driveshaft of a power plant pump with known torque and power transmitted.

Find: Determine the net force applied by the belt on the pulley, in kN, and the rotational speed of the driveshaft, in RPM.

Schematic and Given Data:



Engineering Model:
(1) The rotational speed of the pulley and drive shaft are assumed to be equal.
(2) Net tangential force (F_T) on the pulley is due to belt tension (see schematic).

Analysis:

The net force, in kN, applied by the belt on the pulley is calculated using the torque and the diameter of the pulley as follows

$$\tau = F_T\left(\frac{D}{2}\right) \text{ or } F_T = \frac{2\tau}{D} = \frac{2(200\text{N}\cdot\text{m})}{0.15\text{m}}\left|\frac{1\text{ kN}}{1000\text{N}}\right| = 2.67\text{ kN} \quad \longleftarrow$$

Using Eq. 2.20, the rotational speed of the driveshaft, in RPM, is determined using assumption 1, power transmitted, and torque as follows:

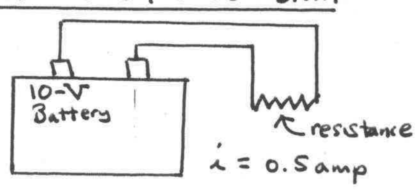
$$\dot{W}_{\text{shaft}} = \tau\omega \quad \text{or} \quad \omega = \frac{\dot{W}_{\text{shaft}}}{\tau} = \frac{7\text{kW}}{200\text{N}\cdot\text{m}}\left|\frac{1000\frac{\text{J}}{\text{s}}}{1\text{kW}}\right|\left|\frac{1\text{N}\cdot\text{m}}{1\text{J}}\right|\left|\frac{60\text{s}}{1\text{min}}\right|\left|\frac{\text{rev}}{2\pi\text{ radians}}\right| = 334.2\text{ RPM} \quad \longleftarrow$$

PROBLEM 2.37

KNOWN: Operating data are given for a 10-V battery providing current to a resistance.

FIND: Determine the resistance, in ohms, and the amount of energy transfer by work, in kJ.

SCHEMATIC & GIVEN DATA:



ANALYSIS:

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} = \frac{10\text{ volts}}{0.5\text{amp}}\left|\frac{1\text{ ohm}}{1\text{ volt/amp}}\right| = 20\text{ ohm} \longleftarrow$$

With Eq. 2.21 applied to the battery, which is discharging,

$$\dot{W} = (\text{voltage})(\text{current}) = (10\text{volt})(0.5\text{amp})\left|\frac{1\text{ Watt/amp}}{1\text{ volt}}\right| = 5\text{ Watt}$$

Then, for 30 minutes of operation,

$$W = \int \underbrace{\dot{W}}_{\text{constant}} dt = (5\text{ watt})(30\text{min.})\left|\frac{60\text{s}}{1\text{min}}\right|\left|\frac{1\text{ J/s}}{1\text{ Watt}}\right|\left|\frac{1\text{kJ}}{10^3\text{J}}\right| = 9\text{ kJ} \longleftarrow$$

PROBLEM 2.38

KNOWN: An expression for the power developed by an automobile engine in terms of torque and rotational speed is given.

FIND: For power, in hp, torque, in ft·lbf, and rotational speed, in RPM, evaluate the value and units of the constant appearing in the given expression.

ANALYSIS: The given expression is $\dot{W} = \mathcal{T}\omega / C$. When $\dot{W}$ is in hp, $\mathcal{T}$ is in ft·lbf, and ω is in RPM, by inspection the units of C are $\left[\frac{(\text{ft}\cdot\text{lbf})(\text{rev/min})}{\text{hp}}\right] \longleftarrow$

Beginning with $\dot{W} = \mathcal{T}\omega$, Eq. 2.20, and applying unit conversion factors for the product $\mathcal{T}\omega$, we get

$$\underbrace{\dot{W}}_{\text{in hp}} = \mathcal{T}(\text{ft}\cdot\text{lbf})\,\omega\left(\frac{\text{rev}}{\text{min}}\right)\left|\frac{2\pi\text{ rad}}{1\text{ rev}}\right|\left|\frac{1\text{ min}}{60\text{s}}\right|\left|\frac{1\text{ hp}}{550\text{ ft}\cdot\text{lbf/s}}\right|$$

$$= \mathcal{T}(\text{ft}\cdot\text{lbf})\,\omega\left(\frac{\text{rev}}{\text{min}}\right)\left[\frac{1\text{ hp}}{5252(\text{ft}\cdot\text{lbf})(\text{rev/min})}\right]$$

$$\therefore \underbrace{\dot{W}}_{\text{in hp}} = \frac{\tau(\text{ft}\cdot\text{lbf})\,\omega\left(\frac{\text{rev}}{\text{min}}\right)}{C}$$

where

$$C = 5252\,\frac{(\text{ft}\cdot\text{lbf})(\text{rev/min})}{\text{hp}} \longleftarrow$$