Chapter 1: Introduction

1-13. The value g = 9.81 m/s^2 is specific to the force of gravity on the surface of the earth. The universal formula for the force of gravitational attraction is:

$$F = G\frac{m_2 m_2}{r^2}$$

Where m_1 and m_2 are the masses of the two objects, r is the distance between the centers of the two objects, and G is the universal gravitation constant, $G = 6.674 \times 10^{-11}$ N(m/kg)^2.

A. Research the diameters and masses of the Earth and Jupiter.
B. Demonstrate that $F = m(9.81 \text{ m/s}^2)$ is a valid relationship on the surface of the earth.
C. Determine the force of gravity acting on a 1000 kg satellite that is 2000 miles above the surface of the Earth.
D. One of the authors of this book has a mass of 200 lb$_m$. If he was on the surface of Jupiter, what gravitational force in lb$_f$ would be acting on him?

Solution:

A. Measurements obtained from different sources will vary slightly.

D_{Earth} ~ 12,742 km $D_{Jupiter}$ ~ 142,000 km

$Mass_{Earth} = 5.97 \times 10^{24}$ kg $Mass_{Jupiter} = 1.90 \times 10^{27}$ kg

B. $Mass_{Earth} = 5.97 \times 10^{24}$ kg $Radius_{Earth} = 6.371 \times 10^6$ meters

$$F = G\frac{m_2 m_2}{r^2} \rightarrow F = m_{\text{object}}\left(6.674 \times 10^{-11}\frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)\frac{5.97 \times 10^{24}\text{ kg}}{(6.37 \times 10^6\text{ m})^2}\left(\frac{\text{N}\cdot\text{s}^2}{\text{kg}\cdot\text{m}}\right)$$

$$\therefore F = m\left(9.81\frac{\text{m}}{\text{s}^2}\right)$$

C. Using the universal gravitational attraction formula:

$$F = G\frac{m_1 m_2}{r^2}$$

$$F = \left(6.674 \times 10^{-11}\frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}\right)\frac{(1000\text{ kg})(5.97 \times 10^{24}\text{ kg})}{(6.371 \times 10^6\text{ m} + 3200\text{ km})^2}$$

$$\boldsymbol{F = 4350\text{ N}}$$

D. $Radius_{Jupiter}$= 71000000 m $Mass_{Jupiter}$= 1.898×10^{27} kg

$$F = G\frac{m_1 m_2}{r^2}$$

$$F = \left(6.674 \times 10^{-11}\,\frac{\mathrm{N \cdot m^2}}{\mathrm{kg^2}}\right)\frac{(90\ \mathrm{kg})(1.898 \times 10^{27}\ \mathrm{kg})}{(6.371 \times 10^{7}\ \mathrm{m})^2}$$

$$\boldsymbol{F = 2809\ \mathrm{N}}$$

1-14. A gas at T = 300 K and P = 100 kPa is contained in a rigid, rectangular vessel that is 2 meters long, 1 meter wide and 1 meter deep. How much force does the gas exert on the walls of the container?

Solution:

First, 1 bar = 100,000 Pa.

From physics, pressure is force per area. Therefore, force is pressure multiplied by area:

$$P = \frac{F}{A} \rightarrow F = PA$$

From geometry:

$$A_{\text{surface}} = 2WH + 2WL + 2HL$$

$$A_{\text{surface}} = 2(1\ \mathrm{m})(1\ \mathrm{m}) + 2(1\ \mathrm{m})(2\ \mathrm{m}) + 2(1\ \mathrm{m})(2\ \mathrm{m})$$

$$A_{\text{surface}} = 10\ \mathrm{m^2}$$

$$F = PA = (100{,}000\ \mathrm{Pa})(10\ \mathrm{m^2})\left(\frac{\mathrm{N}}{\mathrm{Pa \cdot m^2}}\right)$$

$$F = 1000000\ \mathrm{N} = 1\ \mathrm{MN}$$

1-15. A car weighs 1360 kg, and is travelling 96 km/h when it has to make an emergency stop. The car comes to a stop 5 seconds after the brakes are applied.

A. Assuming the rate of deceleration is constant, what force is required?
B. Assuming the rate of deceleration is constant, how much distance is covered before the car comes to a stop?

Solution:

A. First we convert to SI units:

$$v = 96\ \frac{\text{km}}{\text{h}}\left(1000\ \frac{\text{m}}{\text{km}}\right)\left(\frac{1}{3600}\frac{\text{s}}{\text{h}}\right) = 26.667\ \frac{\text{m}}{\text{s}}$$

$$F = Ma$$

$$a = \frac{\Delta v}{t}$$

$$a = \frac{26.7\ \frac{\text{m}}{\text{s}} - 0}{5\ \text{s}}$$

$$a = 5.333\ \frac{\text{m}}{\text{s}^2}$$

$$F = (1360\ \text{kg})\left(5.333\frac{\text{m}}{\text{s}^2}\right)\left(\frac{\text{N}\cdot\text{s}^2}{\text{kg}\cdot\text{m}}\right)$$

$$\boldsymbol{F = 7253\ \text{N}}$$

B. Applying the equations of linear motion from physics:

$$x = a\frac{(\Delta t)^2}{2} + v_0\Delta t + x_0$$

$$x = \left(-5.333\ \frac{\text{m}}{\text{s}^2}\right)\frac{(5\ \text{s})^2}{2} + \left(26.7\ \frac{\text{m}}{\text{s}}\right)(5\ \text{s}) + 0$$

$$\boldsymbol{x = 67.\,\text{m}}$$

1-16. Solar panels are installed on a rectangular flat roof. The roof is 4 meters by 9 meters, and the mass of the panels and framing is 408 kg.

A. Assuming the weight of the panels is evenly distributed over the roof, how much pressure does the solar panel array place on the roof?
B. The density of fallen snow varies; here assume its ~30% of the density of liquid water. Estimate the total pressure on the roof if 0.1 m of snow fall on top of the solar panels.

Solution:

A. From the definitions of pressure and force:

$$P = \frac{F}{A}$$

$$F = Ma$$

$$F = (408\ \mathrm{kg})\left(9.81\ \frac{\mathrm{m}}{\mathrm{s}^2}\right)\left(\frac{\mathrm{N}\cdot\mathrm{s}^2}{\mathrm{kg}\cdot\mathrm{m}}\right) = 4002.\ \mathrm{N}$$

$$P = \frac{4002.\ \mathrm{N}}{(4\ \mathrm{m})(9\ \mathrm{m})}\left(\frac{\mathrm{Pa}\cdot\mathrm{m}^2}{\mathrm{N}}\right)$$

$$\boldsymbol{P = 111.2\ \mathrm{Pa}}$$

B. We first obtain the density of the snow:

$$\rho_{\mathrm{snow}} = 0.30\rho_{\mathrm{water}} = 0.30\left(1000\ \frac{\mathrm{kg}}{\mathrm{m}^3}\right)$$

$$\rho_{\mathrm{snow}} = 300\frac{\mathrm{kg}}{\mathrm{m}^3}$$

Next, we use the density to determine the mass of the snow on the panels:

$$M_{\mathrm{snow}} = \rho_{\mathrm{snow}}V_{\mathrm{snow}} = \rho_{\mathrm{snow}}(H_{\mathrm{snow}}W_{\mathrm{snow}}D_{\mathrm{snow}})$$

$$M_{\mathrm{snow}} = \left(300\frac{\mathrm{kg}}{\mathrm{m}^3}\right)(4\ \mathrm{m})(9\ \mathrm{m})(0.1\ \mathrm{m})$$

$$M_{\mathrm{snow}} = 1080\ \mathrm{kg}$$

Over a metric ton of snow is on the roof. Now, we add it to the mass of the solar panels and find the force and then pressure:

$$M_{\mathrm{on\ roof}} = M_{\mathrm{snow}} + M_{\mathrm{panels}} = 1080\ \mathrm{kg} + 408\ \mathrm{kg} = 1488\ \mathrm{kg}$$

$$F = Ma = M_{\mathrm{on\ roof}}g = (1488\ \mathrm{kg})\left(9.81\frac{\mathrm{m}}{\mathrm{s}^2}\right)\left(\frac{\mathrm{N}\cdot\mathrm{s}^2}{\mathrm{kg}\cdot\mathrm{m}}\right)$$

$$F = 14600\ \mathrm{N}$$

$$P = \frac{F}{A} = \frac{14600\ \mathrm{N}}{(4\ \mathrm{m})(9\ \mathrm{m})}$$

$$\boldsymbol{P = 406.\ \mathrm{Pa}}$$

1-17. A box has a mass of 20 kg, and a building has a height of 15 meters.

A. Find the force of gravity acting on the box.
B. Find the work required to lift the box from the ground to the roof of the building.
C. Find the potential energy of the box when it is on the roof of the building.
D. If the box is dropped off the roof of the building, find the kinetic energy and velocity of the box when it hits the ground.

Solution:

A. A simple application of Newton's second law

$$F = Ma = (20\text{ kg})\left(9.81\frac{\text{m}}{\text{s}^2}\right)\left(\frac{\text{N}\cdot\text{s}^2}{\text{kg}\cdot\text{m}}\right)$$

$$\boldsymbol{F = 196.2\ \textbf{N}}$$

B. Applying the definition of work:

$$W = \int F\,dl$$

The force opposing the motion is that caused by the acceleration of gravity, and the limits of integration are the ground and the roof of the building, so:

$$W = \int F\,dl = \int_{0\text{ m}}^{15\text{ m}} Ma\,dl$$

Mass and acceleration are constant (you can verify the latter by using the universal gravitation formula to find the force of gravity at the top and bottom of the building), so we remove them from the integrand and integrate:

$$W = Ma\int_{0\text{ m}}^{15\text{ m}} dl = Ma(15\text{ m} - 0\text{ m})$$

$$W = Ma(15\text{ m} - 0\text{ m}) = (20\text{ kg})\left(9.81\frac{\text{m}}{\text{s}^2}\right)(15\text{ m})\left(\frac{\text{N}\cdot\text{s}^2}{\text{kg}\cdot\text{m}}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)$$

$$\boldsymbol{W = 2943\ \textbf{J}}$$

C. Again using the definition from the chapter:

$$P.E. = Mgh = (20\text{ kg})\left(9.81\frac{\text{m}}{\text{s}^2}\right)(15\text{ m})\left(\frac{\text{N}\cdot\text{s}^2}{\text{kg}\cdot\text{m}}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)$$

$$\boldsymbol{P.E. = 2943\ \textbf{J}}$$

D. We know that energy is conserved, so if the box is dropped from a height of 15 meters, its kinetic energy at 0 meters will be the same as its potential energy at 15 meters.

$$(\boldsymbol{K.E.})_{\textbf{hitting ground}} = (\boldsymbol{P.E.})_{\textbf{on roof}} = \mathbf{2943\ J}$$

To find the velocity of the box as it hits the ground, we apply the definition of kinetic energy:

$$K.E. = \frac{1}{2}Mv^2$$

$$v = \sqrt{2\frac{(K.E.)}{M}}$$

$$v = \sqrt{2\frac{2943\ \mathrm{J}}{20\ \mathrm{kg}}\left(\frac{\mathrm{kg\cdot m}}{\mathrm{N\cdot s^2}}\right)\left(\frac{\mathrm{N\cdot m}}{\mathrm{J}}\right)}$$

$$v = \sqrt{2\frac{2943\ \mathrm{J}}{20\ \mathrm{kg}}\left(\frac{\mathrm{kg\cdot m}}{\mathrm{N\cdot s^2}}\right)\left(\frac{\mathrm{N\cdot m}}{\mathrm{J}}\right)}$$

We discard the negative root as being impossible (negative velocity would mean the box is accelerating into the sky!).

$$v = 17.16\ \frac{\mathrm{m}}{\mathrm{s}}$$

1-18. 100 kg of steam is enclosed in a piston-cylinder device, initially at 573.15 K and 0.5 MPa. It expands and cools to 473.15 K and 0.1 MPa.

A. What is the change in internal energy of the steam in this process?
B. If the external pressure is constant at 0.1 MPa, how much work was done by the steam on the surroundings?
C. Research and briefly describe at least two examples of machines, either historical or currently in use, that harness the energy in steam and convert it into work. Any form of work is acceptable; you needn't confine your research to expansion work (which was examined in parts A and B).

Solution:

A. Let's use the steam tables to find out the specific internal energy of the system:

$$\hat{U}_1 = 2803.2\ \frac{\mathrm{kJ}}{\mathrm{kg}}$$

$$\hat{U}_2 = 2658.2\ \frac{\text{kJ}}{\text{kg}}$$

$$\Delta U = M\Delta\hat{U} = (100\ \text{kg})\left(2658.2\ \frac{\text{kJ}}{\text{kg}} - 2803.2\ \frac{\text{kJ}}{\text{kg}}\right)$$

$$\boldsymbol{\Delta U = -14,500\ \textbf{kJ} = -14.5\ \textbf{MJ}}$$

B. Again we go to the steam tables to find the specific volumes of the steam at the two states:

$$\hat{V}_1 = 0.5226\ \frac{\text{m}^3}{\text{kg}}$$

$$\hat{V}_2 = 2.1724\ \frac{\text{m}^3}{\text{kg}}$$

Thus the gas expands, and work is described by Equation 1.22:

$$W_{\text{EC}} = -\int P\,dV$$

The pressure opposing the expansion is constant, so we factor it out of the integral and integrate between the two volumes:

$$W_{\text{EC}} = -P\int_{V_1}^{V_2} dV = -P(V_2 - V_1) = -PM\left(\hat{V}_2 - \hat{V}_1\right)$$

$$W_{\text{EC}} = -(0.1\ \text{MPa})(100\ \text{kg})\left(2.1724\ \frac{\text{m}^3}{\text{kg}} - 0.5226\ \frac{\text{m}^3}{\text{kg}}\right)\left(\frac{\text{N}}{\text{Pa}\cdot\text{m}^2}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)$$

$$\boldsymbol{W_{\textbf{EC}} = -16.5\ \textbf{MJ}}$$

The negative sign indicates work is transferred from gas to the surroundings.

C. Steam power is still used in electrical generators that run on the Rankine cycle with water as the operating fluid. Historically, steam engines have been used to power systems like pumps, boats, trains, sawmills etc. The common feature in these machines is they require shaft work that can be supplied by steam turbines.

1-19.

A. An object is dropped from a height of 6 meters off the ground. What is its velocity when it hits the ground?

B. Instead of being dropped, the object is thrown down, such that when it is 6 m off the ground, it already has an initial velocity of 6 m/s straight down. What is its velocity when it hits the ground?
C. What did you assume in answering questions A and B? Give at least three examples of objects for which your assumptions are very good, and at least one example of an object for which your assumptions would fail badly.

Solution:

A. Energy is conserved and only kinetic and potential energies experience change, so:

$$\Delta P.E. + \Delta K.E. = 0$$

We know that kinetic energy is zero at the start and potential energy is zero at the end, so:

$$Mgh_1 = \frac{1}{2}Mv_2^2$$

Note that the mass of the object cancels out of the equation. We now solve for velocity:

$$v_2 = \sqrt{2gh_1}$$

$$v_2 = \sqrt{2\left(9.81\,\frac{\mathrm{m}}{\mathrm{s}^2}\right)(6\ \mathrm{m})}$$

$$\boldsymbol{v_2 = 10.8\,\frac{\mathbf{m}}{\mathbf{s}}}$$

B. Energy is conserved and only kinetic and potential energies experience change, so:

$$\Delta P.E. + \Delta K.E. = 0$$

Unlike part A, kinetic energy is *not* zero at the start of the fall.

$$Mgh = \frac{1}{2}Mv_2^2 - \frac{1}{2}Mv_1^2$$

Cancel mass and rearrange:

$$gh = \frac{1}{2}v_2^2 - \frac{1}{2}v_1^2$$

$$v_2^2 = 2gh + v_1^2$$

$$v_2^2 = \sqrt{2gh + v_1^2}$$

Solving:

$$v_2 = \sqrt{2\left(9.81\,\frac{\text{m}}{\text{s}^2}\right)(6\text{ m}) + \left(6\,\frac{\text{m}}{\text{s}}\right)^2}$$

$$\boldsymbol{v_2 = 14.2\,\frac{\textbf{m}}{\textbf{s}}}$$

C. Air resistance was ignored. This is reasonable for most objects (e.g., brick, piece of wood, can of beans), but wouldn't work for something with a high surface area to mass ratio, such as a piece of paper or a feather.

1-20. An airplane is 6 km above the ground when a 100 kg object is dropped from it. If there were no such thing as air resistance, what would the vertical velocity and kinetic energy of the dropped object be when it hits the ground?

Solution:

Energy is conserved and only kinetic and potential energies experience change, so:

$$\Delta P.E. + \Delta K.E. = 0$$

We know that kinetic energy is zero at the start and potential energy is zero at the end, so:

$$Mgh = \frac{1}{2}Mv^2$$

Note that the mass of the object cancels out of the equation. We now solve for velocity:

$$v = \sqrt{2gh}$$

$$v = \sqrt{2\left(9.81\,\frac{\text{m}}{\text{s}^2}\right)(6000\text{ m})}$$

$$\boldsymbol{v = 343\,\frac{\textbf{m}}{\textbf{s}}}$$

Now we can solve for kinetic energy directly:

$$K.E. = \frac{1}{2}Mv^2$$

$$K.E. = \frac{1}{2}(100\text{ kg})\left(343\,\frac{\text{m}}{\text{s}}\right)^2\left(\frac{\text{N}\cdot\text{s}^2}{\text{kg}\cdot\text{m}}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)$$

$$\boldsymbol{K.E. = 5.9\ \textbf{MJ}}$$

1-21. A filtration system continuously removes water from a swimming pool, passes the water through filters and then returns it to the pool. Both pipes are located near the surface of the water. The flow rate is 1 dm^3 per second. The water entering the pump is at a gauge pressure of 0 Pa, and the water leaving the pump is at a gauge pressure of 70 kPa.

A. The diameter of the pipe that leaves the pump is 0.02 m. How much flow work is done by the water as it leaves the pump and enters the pipe?
B. The water returns to the pool through an opening that is 0.04 inches in diameter, located at the surface of the water, where the pressure is 101.325 kPa. How much work is done by the water as it leaves the pipe and enters the pool?
C. “The system” consists of the water in the pump and in the pipes that transport water between the pump and the pool. Is the system at steady state, equilibrium, both, or neither?

Solution:

A. Using Equation 1.28, we can calculate flow work. Remember to use absolute pressure for thermodynamic equations.

$$\dot{W} = P\dot{V}$$

$$\dot{W} = (171325\ \text{Pa})\left(0.1\ \frac{\text{m}^3}{\text{s}}\right)\left(\frac{\text{N}}{\text{Pa}\cdot\text{m}^2}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)\left(\frac{\text{W}\cdot\text{s}}{\text{J}}\right)$$

$$\boldsymbol{\dot{W} = 17.1\ \text{kW}}$$

B. Similarly to part A, only at atmospheric pressure:

$$\dot{W} = P\dot{V}$$

$$\dot{W} = (101325\ \text{Pa})\left(0.1\ \frac{\text{m}^3}{\text{s}}\right)\left(\frac{\text{N}}{\text{Pa}\cdot\text{m}^2}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)\left(\frac{\text{W}\cdot\text{s}}{\text{J}}\right)$$

$$\boldsymbol{\dot{W} = 10.1\ \text{kW}}$$

C. Based upon the problem description, it might appear that this system is operating at steady state; the parameters of the system (flow rates, pressures) as described do not change with time. However, if the filter system is working as described, then the water coming in is dirty and the water leaving the filtration system is cleaner, and anything that is removed from the water is accumulating in the filter. If mass is accumulating in the system then it is not at steady state.

The system is not at equilibrium with the surroundings because the conditions of the liquid leaving the pipe (70 kPa) are significantly different from the water at the surface of the pool (0 Pa); there is a significant pressure difference between the system and the surroundings at this point.

1-22. The Reaumur temperature scale, while now obscure, was once in common use in some parts of the world. The normal freezing point of water is defined as 0 degrees Reaumur and the normal boiling point of water is defined as 80 degrees Reaumur.
Tolstoy's *War and Peace* mentions the temperature "minus 20 degrees Reaumur." What is this in Celsius, Fahrenheit, Kelvin and Rankine?

Solution:

The interval between the freezing and boiling points of water is 80° Reaumur, 100° Celsius and 180°F. Consequently, one degree Reaumur is equal in magnitude to 1.25 (100/80) degrees Celsius or 2.25 degrees Fahrenheit. 0° Reaumur is equivalent to 0°C, 32°F, 273 K or 492 Rankine. Therefore:

Reaumur (°Re)	**Celsius (°C)**	**Fahrenheit (°F)**	**Rankine (°R)**	**kelvins (K)**
–20	–25	–23	447	248

1-23. Use the data in the steam table to answer the following:

A. Find the change in internal energy when 100 kg of steam at constant pressure P = 0.1 MPa has its temperature reduced from 573.15 K to 373.15 K.
B. Find the change in internal energy when 100 kg of liquid water at constant pressure P = 20 MPa has its temperature increased from 513.15 K to 573.15 K.
C. Energy was transferred from the system in part A, and transferred to the system in part B. What form would you expect these energy transfers took?
D. Your answers to parts A and B should be similar in magnitude, though different in sign. Would it be possible to accomplish both of the processes in parts A and B simultaneously, by taking most of the energy that was removed from the steam described in part A and transferring it to the liquid water described in part B?

Solution:

A. Referring to the appendix containing the steam tables:

$$\hat{U}_1 = 2810.6\ \frac{\text{kJ}}{\text{kg}}$$

$$\hat{U}_2 = 2506.2\ \frac{\text{kJ}}{\text{kg}}$$

$$\Delta U = M\Delta\hat{U} = (100\text{ kg})\left(2506.2\ \frac{\text{kJ}}{\text{kg}} - 2810.6\ \frac{\text{kJ}}{\text{kg}}\right)$$

$$\boldsymbol{\Delta U = -30,440\text{ kJ} = -30.44\text{ MJ}}$$

B. Referring again to the steam tables:

$$\hat{U}_1 = 1016.1\ \frac{\text{kJ}}{\text{kg}}$$

$$\hat{U}_2 = 1307.1\ \frac{\text{kJ}}{\text{kg}}$$

$$\Delta U = M\Delta\hat{U} = (100\text{ kg})\left(1307.1\ \frac{\text{kJ}}{\text{kg}} - 1016.1\ \frac{\text{kJ}}{\text{kg}}\right)$$

$$\boldsymbol{\Delta U = 29,100\text{ kJ} = 29.1\text{ MJ}}$$

C. The large temperature changes can be accomplished largely or entirely with heat transfers. In part A, some work would also be transferred if for example this process was occurring in a closed system; since the temperature of the gas is changing at constant pressure the volume must also be changing. The change in volume of the liquid in part B, however, is likely negligible.

D. No, because heat transfer requires a temperature driving force. The steam cools all the way to 373.15 K, and there is no way it can transfer heat to the liquid after it has fallen below 513.15 K.

1-24. A balloon is inflated from a negligible initial volume to a final volume of 200 cm^3. How much work is done by the balloon on the surroundings if the pressure opposing the expansion is

A. P = 0.1 MPa
B. P = 0.05 MPa
C. P = 0 MPa
D. P = 0.3 MPa
E. Can you think of locations where each of the "surroundings" pressures given in parts A-D would be realistic?

Solution:

A. Work of expansion or contraction is described by Equation 1.22:

$$W_{\text{EC}} = -\int P\,dV$$

The pressure opposing the expansion is constant, so we factor it out of the integral and integrate between the two volumes:

$$W_{\mathrm{EC}} = -P \int_{V_1}^{V_2} dV = -P(V_2 - V_1)$$

$$W_{\mathrm{EC}} = -(0.1\ \mathrm{MPa})(200\ \mathrm{cm}^3 - 0\ )\left(\frac{1}{10^6}\frac{\mathrm{m}^3}{\mathrm{cm}^3}\right)\left(\frac{\mathrm{N}}{\mathrm{Pa}\cdot\mathrm{m}^2}\right)\left(\frac{\mathrm{J}}{\mathrm{N}\cdot\mathrm{m}}\right)\left(\frac{10^6\ \mathrm{Pa}}{\mathrm{MPa}}\right)$$

$$\boldsymbol{W_{\mathrm{EC}} = -20\ \mathrm{J}}$$

The negative sign indicates work is transferred from gas to the surroundings.

B. Work of expansion or contraction is described by Equation 1.22:

$$W_{\mathrm{EC}} = -\int P\, dV$$

The pressure opposing the expansion is constant, so we factor it out of the integral and integrate between the two volumes:

$$W_{\mathrm{EC}} = -P \int_{V_1}^{V_2} dV = -P(V_2 - V_1)$$

$$W_{\mathrm{EC}} = -(0.05\ \mathrm{MPa})(200\ \mathrm{cm}^3 - 0\ )\left(\frac{1}{10^6}\frac{\mathrm{m}^3}{\mathrm{cm}^3}\right)\left(\frac{\mathrm{N}}{\mathrm{Pa}\cdot\mathrm{m}^2}\right)\left(\frac{\mathrm{J}}{\mathrm{N}\cdot\mathrm{m}}\right)\left(\frac{10^6\ \mathrm{Pa}}{\mathrm{MPa}}\right)$$

$$\boldsymbol{W_{\mathrm{EC}} = -10\ \mathrm{J}}$$

The negative sign indicates work is transferred from gas to the surroundings.

C. Work of expansion or contraction is described by Equation 1.22:

$$W_{\mathrm{EC}} = -\int P\, dV$$

The pressure opposing the motion is zero, which makes the entire term zero, so:

$$\boldsymbol{W_{\mathrm{EC}} = 0}$$

D. Work of expansion or contraction is described by Equation 1.22:

$$W_{\mathrm{EC}} = -\int P\, dV$$

The pressure opposing the expansion is constant, so we factor it out of the integral and integrate between the two volumes:

$$W_{\mathrm{EC}} = -P \int_{V_1}^{V_2} dV = -P(V_2 - V_1)$$

$$W_{\mathrm{EC}} = -(0.3\ \mathrm{MPa})(200\ \mathrm{cm}^3 - 0\ )\left(\frac{1}{10^6}\frac{\mathrm{m}^3}{\mathrm{cm}^3}\right)\left(\frac{\mathrm{N}}{\mathrm{Pa}\cdot\mathrm{m}^2}\right)\left(\frac{\mathrm{J}}{\mathrm{N}\cdot\mathrm{m}}\right)\left(\frac{10^6\ \mathrm{Pa}}{\mathrm{MPa}}\right)$$

$$\boldsymbol{W_{\mathrm{EC}} = -60\ \mathrm{J}}$$

The negative sign indicates work is transferred from gas to the surroundings.

E. 0.1 MPa is about atmospheric pressure, so it is a very plausible ambient pressure. A balloon expanding in the vacuum of space would have essentially no opposing pressure and do essentially no work. 0.05 MPa is the atmospheric pressure at approximately 6000 meters above sea level. 0.3 MPa is the pressure under water at a depth of approximately 20 meters.

1-25. "The system" is a large ship and everything inside it. The ship turns off its engines, and is floating in the ocean. No material enters or leaves the ship during the process. Some descriptions of this situation are given below. For each, indicate whether it is true or false, and explain why.

A. The system is not at equilibrium, because equilibrium implies no external forces are acting on the system and the ship has forces acting upon it. The system is at steady state, however, because the forces acting upon it are balanced.

This statement is false. The representation of equilibrium is wrong. Equilibrium does not mean there are "no external forces acting on it," equilibrium means that all forces (and temperatures, etc.) are balanced such that there is no driving force for change.

B. The system is not at equilibrium, because the force of gravity is acting upon the ship but there is no upward force balancing the downward force of gravity. However, the system is at steady state, because it is not moving.

This statement is false. It is true that the force of gravity is acting downward, but the "no upward force" part of the statement is incorrect; the buoyant force of the water is acting upward and balancing the force of gravity. The description of steady-state is ok.

C. The system is both at equilibrium and at steady state, because the ship is not moving, and there is no driving force for motion: the forces acting upon it balance each other and there is no driving force for change.

This statement is true as far as we know. The position of the ship isn't changing and there are no forces acting on the ship that would cause it to move. Nothing is entering or leaving the ship so the mass of the system isn't changing. Thus, the information that we have is consistent with both equilibrium and steady-state. Notice however that only the position of the ship and the fact that it is a closed system are discussed, there is no mention of temperature. If the ship and the surroundings are at different temperatures, then there is no *thermal* equilibrium. If the ship's temperature is increasing or decreasing, then it is not at steady-state.

- **D.** The system is neither at equilibrium nor at steady state, because no object in the ocean is perfectly motionless. The ship bobs up and down with the waves, and likely drifts in a horizontal direction due to currents. If the position of the system is changing, it can't be at steady state or equilibrium.

This statement is literally correct. If an object is bobbing up and down with the waves then it is not perfectly motionless relative to the earth, so its velocity and height are constantly undergoing small changes. It is, however, quite likely that *modeling* the ship as "at equilibrium" and "at steady state" would be reasonable. Ultimately, the question you would have to ask yourself is whether the ship bobbing up and down is a significant amount of motion in the context of whatever problem you are trying to solve.

1-26. "The system" is a large ship and its contents. The inside of the ship and the air outside the ship are at the same temperature. The ship is sailing north at a constant speed of 20 knots. The engines are powered by burning liquid fuel, and the gaseous by-products (primarily carbon dioxide and water) are vented to the atmosphere, but nothing else enters or leaves the system. Some descriptions of this situation are given below. For each, indicate whether it is true or false, and explain why.

- **A.** The system is at steady state, because its velocity is constant. However, it is not at equilibrium- the fact that the ship is moving indicates that the forces are not balanced.

This statement is false. For a system to be at steady state, ALL properties of the system must be constant with respect to time. Here the velocity is constant but the mass of the system is changing.

- **B.** The system is not at steady state, because the amount of fuel inside the system is changing. However, the system is at equilibrium, because it is at the same temperature as the surroundings; there is no driving force for heat transfer.

This statement is false. The description of "steady state" is ok, but the description of equilibrium is incomplete. The temperatures are balanced, so there is thermal equilibrium. The velocity of the ship is constant, so we could say it is in mechanical equilibrium, reasoning that "the velocity is constant, therefore there is no acceleration, and therefore the forces are balanced." However, there is clearly no chemical equilibrium. Inside the system there is a combustion reaction going on, in which liquids are turning into gases and these gases are being expelled from the system. We won't actually study chemical reaction equilibrium quantitatively until chapter 14, but we should recognize chemical reactions, melting, evaporation etc., as changes that are caused by chemical driving forces.

C. The system is neither at equilibrium nor at steady state.

This statement is true. See the answers to A and B.

D. The system is adiabatic, because there is no temperature driving force that would cause heat transfer to occur.

This statement is true. As long as the system and surroundings temperatures are equal to each other there is no heat transfer**.**

E. The system is an isolated system, because nothing is entering it and there is no heat transfer.

This statement is false. An isolated system would have nothing entering *or* exiting; here there is material exiting.

1-27. You are collecting data from the literature on a compound, for which you need to know the specific internal energy at a number of different states. You've found some data from three different sources, but they each use different reference states and the units aren't uniform either. The data is shown in the table below. Fill in all of the empty cells in the table, so that you have correct values of $\hat{\boldsymbol{U}}$ for all seven conditions (A-G) at all three reference states.

State	Phase	T (K)	P (MPa)	$\hat{U}$, source 1	$\hat{U}$, source 2	$\hat{U}$, source 3
A	Solid	290.15	0.1		0	
B	Liquid	290.15	0.1	–18.0 J/g	20,470 ft·lb_f/lb_m	
C	Liquid	298.15	0.1	0		
D	Liquid	355.15	0.1		102,970 ft·lb_f/lb_m	0
E	Vapor	355.15	0.1			67.0 J/g
F	Vapor	373.15	0.133			136.0 J/g
G	Liquid	373.15	0.133			37.0 J/g

Solution:

A much-used conversion factor in this problem is:

$$1\,\frac{\text{J}}{\text{g}} = \left(1\,\frac{\text{J}}{\text{g}}\right)\left(453.6\,\frac{\text{g}}{\text{lb}_\text{m}}\right)\left(\frac{\text{J}}{\text{N}\cdot\text{m}}\right)\left(\frac{1}{4.448}\,\frac{\text{lb}_\text{f}}{\text{N}}\right)\left(\frac{1}{0.3048}\,\frac{\text{ft}}{\text{m}}\right) = 334.6\,\frac{\text{ft}\cdot\text{lb}_\text{f}}{\text{lb}_\text{m}}$$

From source 2:

$$\hat{U}_B - \hat{U}_A = 20{,}470\,\frac{\text{ft}\cdot\text{lb}_\text{f}}{\text{lb}_\text{m}} = 61.2\,\frac{\text{J}}{\text{g}}$$

Applying this result to source 1:

$$\hat{U}_B - \hat{U}_A = 61.2\,\frac{\text{J}}{\text{g}}$$

$$\hat{U}_B = -18.0\,\frac{\text{J}}{\text{g}}$$

$$\therefore \widehat{U}_A = -79.2\,\frac{\mathrm{J}}{\mathrm{g}}$$

From source 1:

$$\widehat{U}_C - \widehat{U}_B = 18\,\frac{\mathrm{J}}{\mathrm{g}} = 6022\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}}$$

Applying this result to source 2:

$$\widehat{U}_C - \widehat{U}_B = 6022\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}}$$

$$\widehat{U}_B = -20{,}470\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}}$$

$$\therefore \widehat{U}_C = -26{,}490\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}}$$

From source 2:

$$\widehat{U}_D - \widehat{U}_C = 102{,}970\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}} - 26{,}490\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}} = 76480\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}} = 228.6\,\frac{\mathrm{J}}{\mathrm{g}}$$

Applying this result to source 1:

$$\widehat{U}_D - \widehat{U}_C = 228.6\,\frac{\mathrm{J}}{\mathrm{g}}$$

$$\widehat{U}_C = 0$$

$$\therefore \widehat{U}_D = 228.6\,\frac{\mathrm{J}}{\mathrm{g}}$$

We now know $\widehat{U}$ for state D relative to all three reference states. Notice that source 1 and
source 3 used the same units, but $\widehat{U}$ is 228.6 J/g higher on the reference state used in source 1. This means the values from source 1 at *all* states will be 228.6 J/g higher than the values for source 3. At this point, $\widehat{U}$ is known for either source 1 or source 3 for every state, so both columns can now be completed.

From source 3:

$$\widehat{U}_E - \widehat{U}_D = 67.0\,\frac{\mathrm{J}}{\mathrm{g}} = 22{,}420\,\frac{\mathrm{ft\cdot lb_f}}{\mathrm{lb_m}}$$

$$\hat{U}_F - \hat{U}_D = 136.0\,\frac{\text{J}}{\text{g}} = 45{,}500\,\frac{\text{ft}\cdot\text{lb}_\text{f}}{\text{lb}_\text{m}}$$

$$\hat{U}_G - \hat{U}_D = 37.0\,\frac{\text{J}}{\text{g}} = 12{,}380\,\frac{\text{ft}\cdot\text{lb}_\text{f}}{\text{lb}_\text{m}}$$

Applying these to Source 2, using the fact that

$$\hat{U}_D = 102{,}970\,\frac{\text{ft}\cdot\text{lb}_\text{f}}{\text{lb}_\text{m}}$$

allows us to complete the table:

State	**Phase**	***T* (K)**	***P* (MPa)**	**$\hat{U}$, source 1**	**$\hat{U}$, source 2**	**$\hat{U}$, source 3**
A	Solid	290.15	0.1	**–79.2 J/g**	0	**–307.8 J/g**
B	Liquid	290.15	0.1	–18.0 J/g	20,470 $\text{ft}\cdot\text{lb}_\text{f}/\text{lb}_\text{m}$	**–246.6 J/g**
C	Liquid	298.15	0.1	0	**26,490 $\text{ft}\cdot\text{lb}_\text{f}/\text{lb}_\text{m}$**	**–228.6 J/g**
D	Liquid	355.15	0.1	**228.6 J/g**	102,970 $\text{ft}\cdot\text{lb}_\text{f}/\text{lb}_\text{m}$	0
E	Vapor	355.15	0.1	**295.6 J/g**	**125,390 $\text{ft}\cdot\text{lb}_\text{f}/\text{lb}_\text{m}$**	67.0 J/g
F	Vapor	373.15	0.133	**364.6 J/g**	**148,470 $\text{ft}\cdot\text{lb}_\text{f}/\text{lb}_\text{m}$**	136.0 J/g
G	Liquid	373.15	0.133	**265.6 J/g**	**115,350 $\text{ft}\cdot\text{lb}_\text{f}/\text{lb}_\text{m}$**	37.0 J/g

Chapter 1: Introduction