CHAPTER 1: INTRODUCTION TO THERMODYNAMICS AND ENERGY

END OF CHAPTER PROBLEM SOLUTIONS

1.1) For the following systems, determine whether the system described is best modeled as an isolated, closed, or open system:
(a) steam flowing through a turbine
(b) an incandescent light bulb
(c) a fuel pump in a moving automobile
(d) an anchor of a sunken ship resting 3000 m below the surface of the ocean
(e) the roof of a house

Solution:
(a) Open System
(b) Closed System
(c) Open System
(d) Isolated System – could be modeled as a closed system if something is being done to it.
(e) Closed System

1.2) For the following systems, determine whether the system described is best modeled as an isolated, closed, or open system:
(a) a tree growing in a forest
(b) a television
(c) a laptop computer
(d) the *Voyager 2* spacecraft in its current state
(e) the *Messenger* spacecraft as it moved into orbit around Mercury

Solution:
(a) Open System
(b) Closed System
(c) Open System (considering the cooling air passing through the system)
(d) Isolated System
(e) Open System (would have been expelling mass with a rocket burn)

1.3) For the following systems, determine whether the system described is best modeled as an isolated, closed, or open system:
(a) an inflated tire
(b) a lawn sprinkler actively in use
(c) a cup filled with liquid water

(d) an engine's radiator
(e) a rock formation 200 m below the surface of the earth

Solution:
(a) Closed System
(b) Open System
(c) Closed System, unless significant evaporation is actively occurring (which would make it an open system)
(d) Open System
(e) Isolated System

1.4) For the following systems, determine whether the system described is best modeled as an isolated, closed, or open system:
(a) a pump supplying water to a building
(b) a tea kettle containing boiling water
(c) an active volcano
(d) a solid gold bar placed inside a very well-insulated box
(e) a chair

Solution:
(a) Open System
(b) Open System
(c) Open System
(d) Isolated System
(e) Closed System

1.5) For the following systems, determine whether the system described is best modeled as an isolated, closed, or open system:
(a) a pulley on an elevator
(b) a bathtub
(c) a human being
(d) a piece of metal being shaped on a lathe
(e) a comet orbiting the Sun in the Oort cloud (the cloud of inactive comets located well beyond the orbits of the planets)

Solution:
(a) Closed System
(b) Open System if being filled or emptied. If it is just sitting as an empty bathtub, it is a closed system.
(c) Open System
(d) Open System

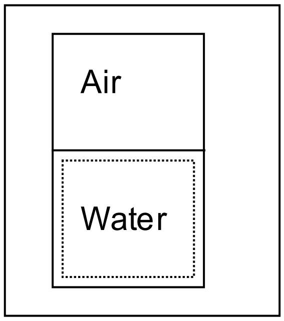
(e) Isolated System

1.6) Consider a closed bottle half-filled with water placed in a refrigerator. Draw diagrams showing the most appropriate system for a thermodynamic analysis that

(a) only considers the water
(b) considers only the water and the air inside the bottle
(c) considers the water and air inside the bottle, and the bottle itself
(d) considers only the bottle and not the contents
(e) considers all the contents of the refrigerator, but not the physical refrigerator

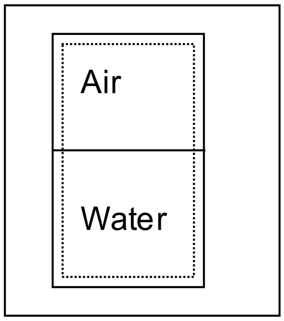
Solution:

(a)



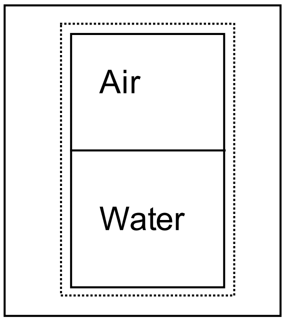
Refrigerator

(b)



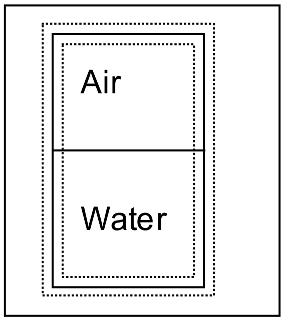
Refrigerator

(c)



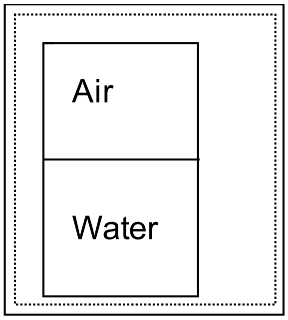
Refrigerator

(d)



Refrigerator

(e)



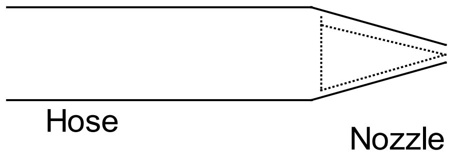
Refrigerator

1.7) Consider a fire hose with water flowing through the hose and then through a nozzle at the end of the hose. Draw diagrams showing the most appropriate system for a thermodynamic analysis that

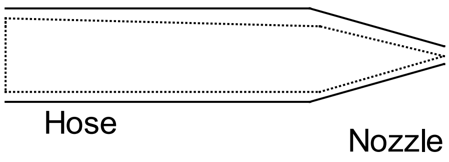
(a) considers only the water in the nozzle of the system
(b) considers the water flowing through the hose and the nozzle
(c) considers both the water flowing through the nozzle, and the nozzle itself

<u>Solution:</u>

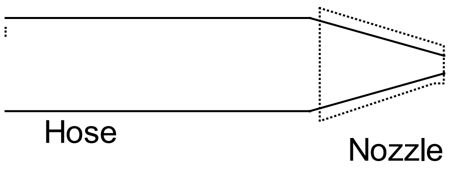
(a)



(b)



(c)



1.8) A basketball is about to leave a player's hand for a shot. Draw diagrams showing the most appropriate system for a thermodynamic analysis that

(a) considers only the air inside the basketball

(b) considers only the material making up the basketball, and not the air inside the ball

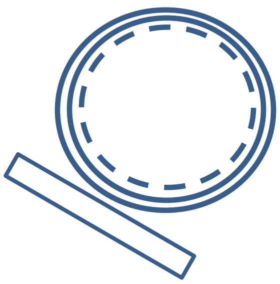
(c) considers the basketball and the air inside

(d) considers the basketball, the air inside, and the player's hand

(e) considers the entire arena in which the basketball is located

Solution:

(a)



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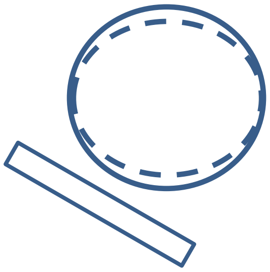

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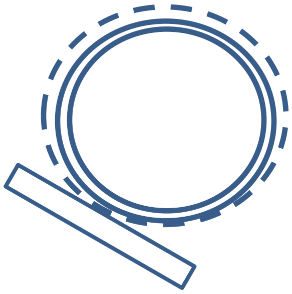

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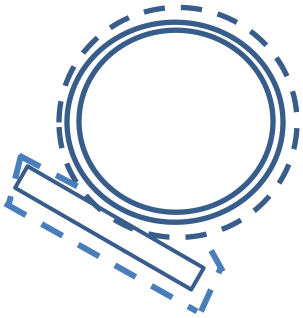


(e)

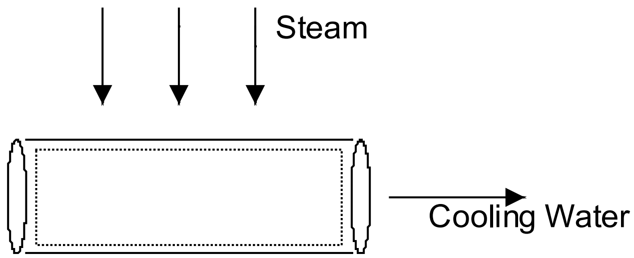
1.9) To condense a flow of steam, liquid cooling water is sent through a pipe, and the steam is passed over the exterior of the pipe. Draw diagrams showing the most appropriate system for a thermodynamic analysis which

(a) considers only the water flowing through the pipe

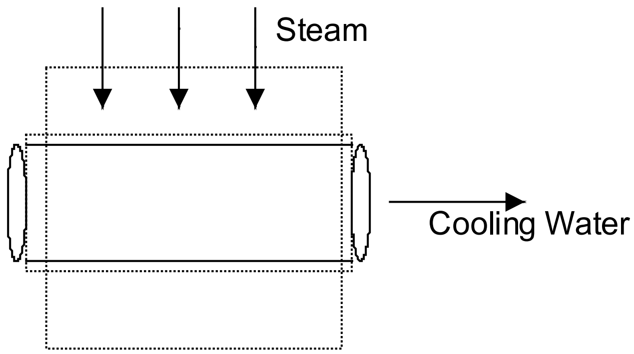
(b) considers only the steam condensing on the exterior of the pipe

(c) considers only the pipe
(d) considers the pipe, the internal cooling water, and the external condensing steam

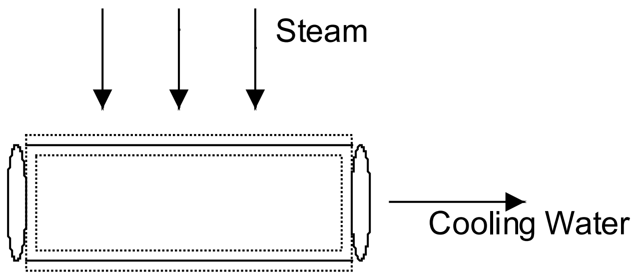
Solution:
(a)



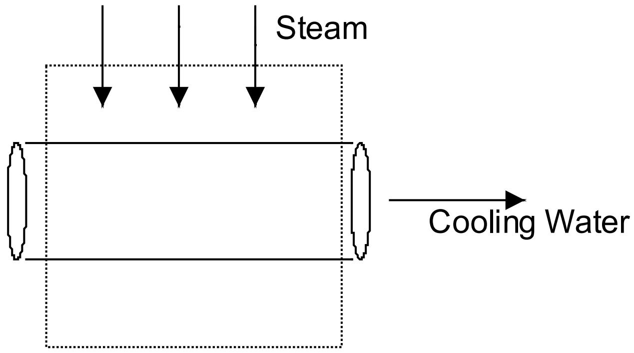
(b)



(c)



(d)

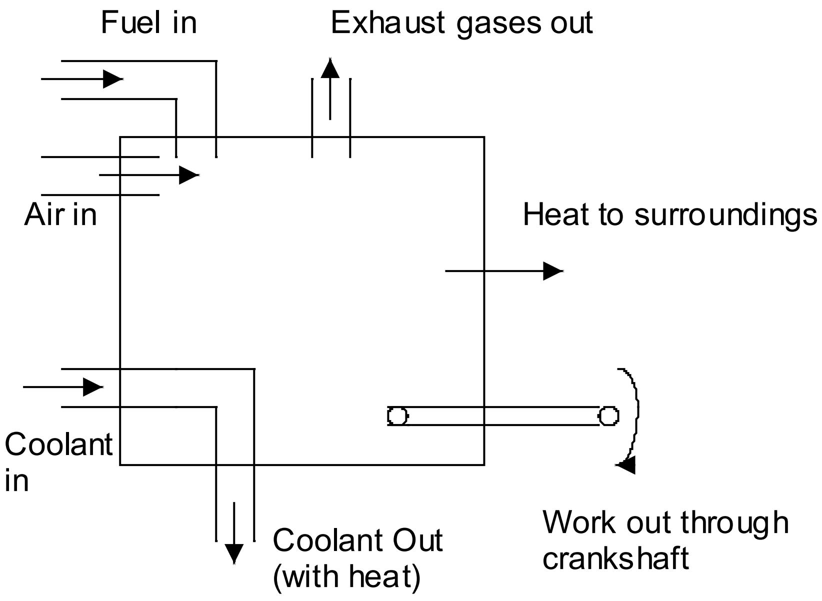


1.10) Draw a schematic diagram of the place where you live. Identify any places where mass or energy may flow into or out of the room or building.

Solution: This answer will vary with student, based on their particular home.

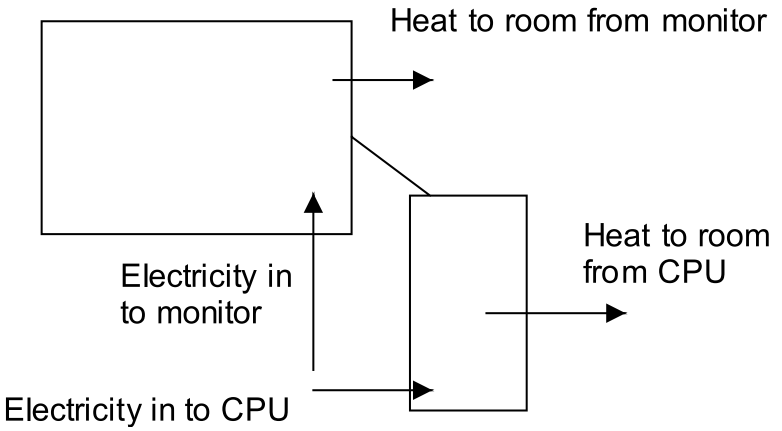
1.11) Draw a schematic diagram of an automobile engine. Identify any locations where mass or energy may flow into or out of the engine.

Solution:



1.12) Draw a schematic diagram of a desktop computer. Identify any locations where mass or energy may flow into or out of the computer.

Solution:

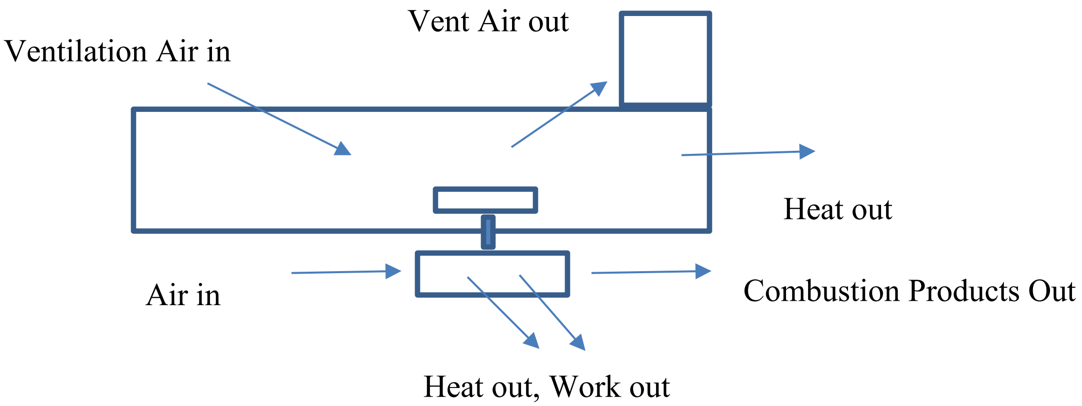


1.13) Draw a schematic diagram of a highway bridge over a river. Identify any mechanisms which may cause mass or energy to flow into or out of the system of the bridge.

Solution:
Potential Mechanisms: Mass – portions of the bridge falling off
Energy – Heating from friction from vehicle tires
Heating from sun
Cooling from wind flowing over the bridge

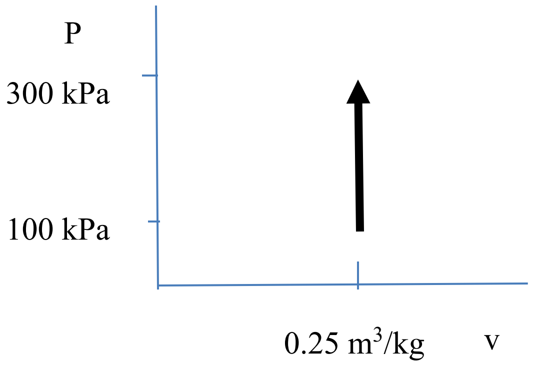
1.14) Draw a schematic diagram of an airplane in flight. Identify any locations where mass or energy may flow into or out of the airplane.

Solution:



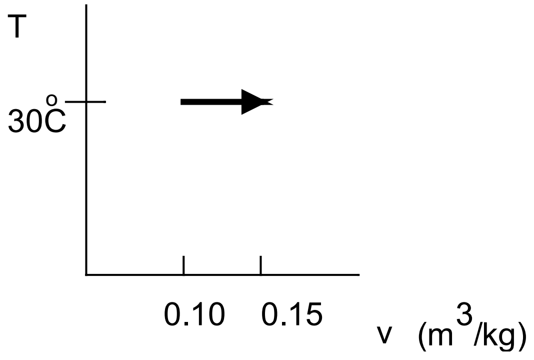
1.15) A closed system undergoes a constant volume (isochoric) process at 0.25 m^3/kg, as the pressure changes from 100 kPa to 300 kPa. Draw this process on a P-v (pressure vs. specific volume) diagram.

Solution:



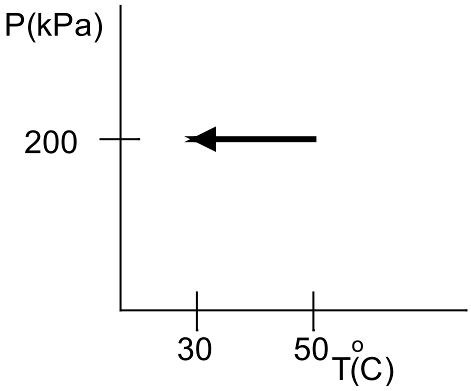
1.16) A system undergoes an isothermal process at 30ºC as the specific volume changes from 0.10 m^3/kg to 0.15 m^3/kg. Draw this process on a *T-v* (temperature vs. specific volume) diagram.

Solution:



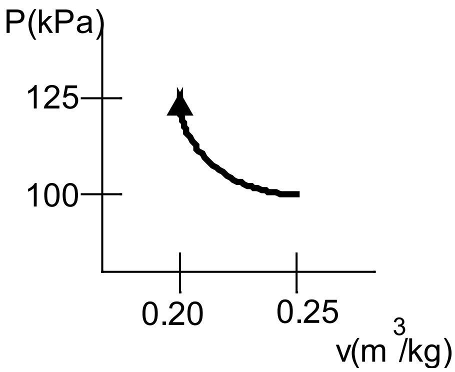
1.17) A system undergoes an isobaric process from 50ºC to 30ºC, at a pressure of 200 kPa. Draw this process on a *P-T* (pressure vs. temperature) diagram.

Solution:



1.18) A system undergoes a process described by *Pv* = constant, from an initial state of 100 kPa and 0.25 m^3/kg, to a final specific volume of 0.20 m^3/kg. Determine the final pressure, and draw this process on a *P-v* (pressure vs. specific volume) diagram.

Given: P_1 = 100 kPa; v_1 = 0.25 m^3/kg; v_2 = 0.20 m^3/kg; Pv = constant
Solution:
As Pv = constant, $P_1v_1 = P_2v_2$
So, $P_2 = P_1 \frac{v_1}{v_2}$ = **125 kPa**

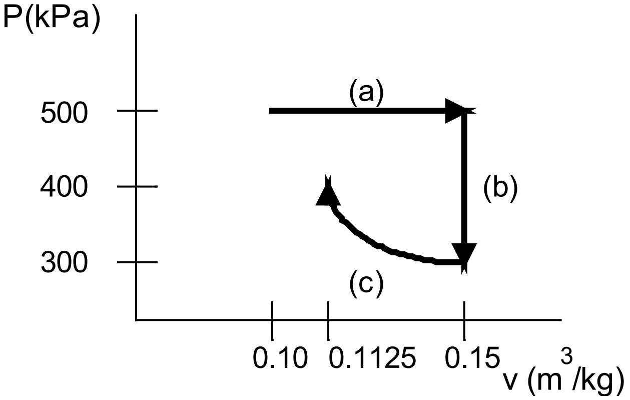


1.19) Draw on a *P-v* diagram the following three sequential processes which a system undergoes:

(a) a constant-pressure expansion from an initial state of 500 kPa and 0.10 m^3/kg to a specific volume of 0.15 m^3/kg
(b) a constant-specific-volume depressurization to a pressure of 300 kPa
(c) a process following *Pv* = constant to a final pressure of 400 kPa

Solution:
From the given information, $P_1 = P_2$ = 500 kPa and P_3 = 300 kPa
$v_2 = v_3$ = 0.15 m^3/kg

And with $P_4 = 400$ kPa, and $v_4 = P_3 v_3 / P_4 = 0.1125\ m^3/kg$



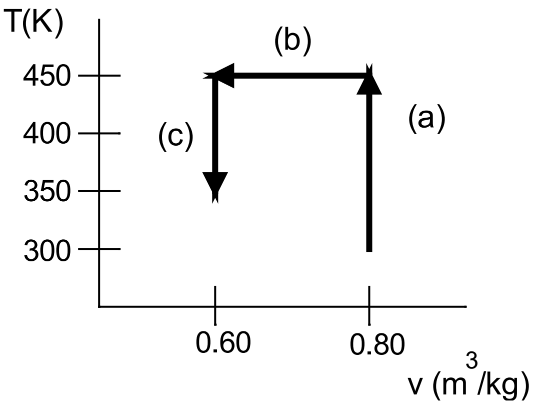
1.20) Draw a *T-v* diagram of the following three sequential processes which a system undergoes:

(a) a constant-specific volume heating from 300 K and 0.80 m^3/kg to a temperature of 450 K

(b) an isothermal compression to a specific volume of 0.60 m^3/kg

(c) an isochoric cooling to 350 K

<u>Solution</u>: $T_1 = 300$ K, $T_2 = 450$ K, $v_1 = v_2 = 0.80\ m^3/kg$
$T_3 = T_2 = 450$ K, $v_3 = 0.60\ m^3/kg = v_4$,
$T_4 = 350$ K

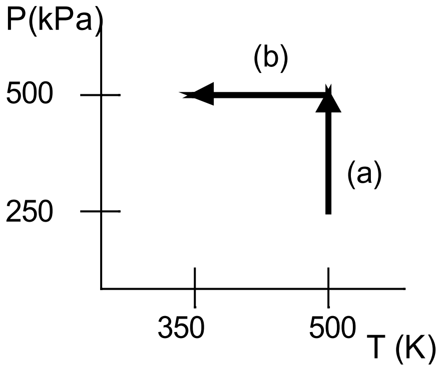


1.21) Draw a *P-T* diagram of a system undergoing the following two processes:

(a) an isothermal compression from 500 K and 250 kPa to a pressure of 500 kPa.

(b) an isobaric cooling to a temperature of 350 K.

<u>Solution</u>:



1.22) Draw a P-v diagram of a closed system undergoing the following four sequential processes:

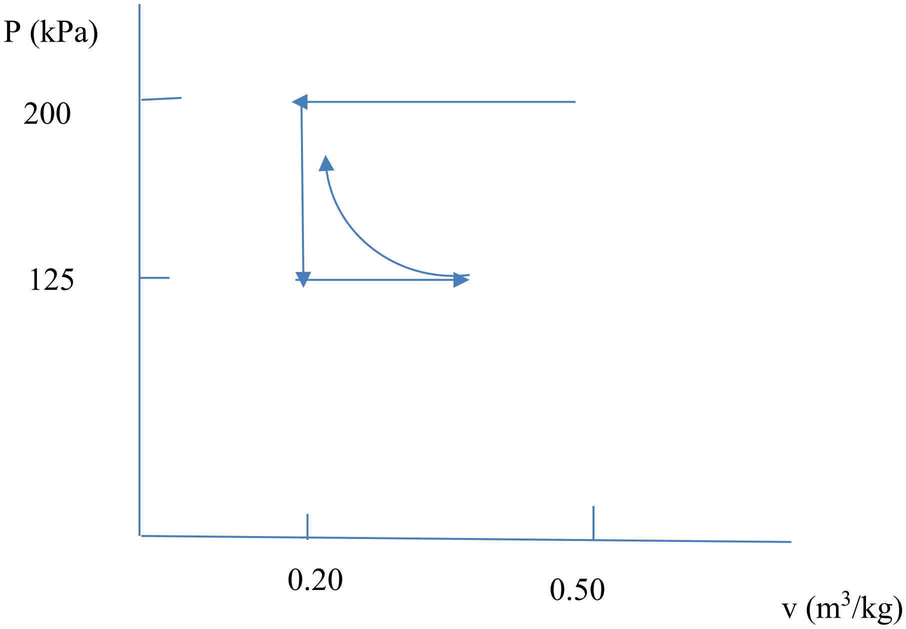
(a) an isobaric compression from 200 kPa and 0.50 m^3/kg to a specific volume of 0.20 m^3/kg

(b) a constant-pressure expansion to a specific volume of 0.30 m^3/kg

(c) a constant-volume depressurization to a pressure of 125 kPa

(d) a constant-pressure expansion to a specific volume of 0.30 m^3/kg

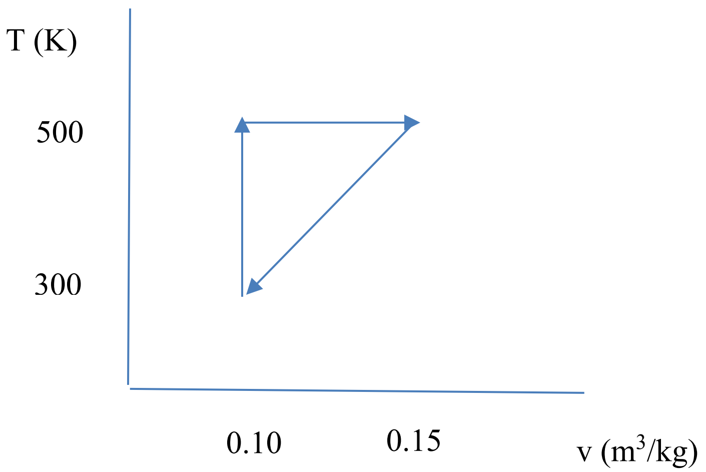
Solution:



1.23) A thermodynamic cycle consists of the following three processes. Draw the cycle on a *T*-*v* diagram.

(a) a constant-volume heating from 0.10 m^3/kg and 300 K to 500 K
(b) an isothermal expansion to a specific volume of 0.15 m^3/kg
(c) a linear process returning the process to its initial state

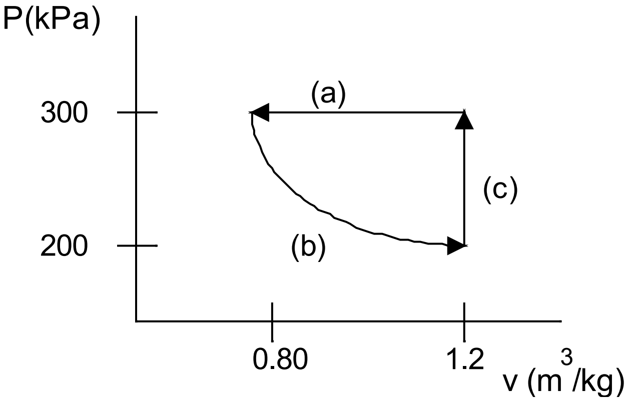
Solution:



1.24) A Thermodynamic cycle consists of the following three processes. Draw the cycle on a *P*-*v* diagram.

(a) An isobaric compression from 300 kPa and 1.20 m^3/kg to a specific volume of 0.80 m^3/kg.
(b) A process for which Pv = constant to a specific volume of 1.20 m^3/kg.
(c) A constant-volume process resulting in a pressure of 300 kPa

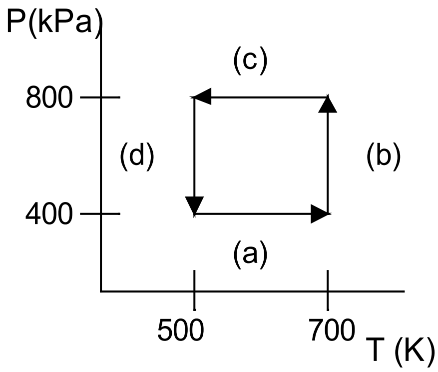
Solution: For process (b), $P_2v_2 = P_3v_3$, so P_3 = 200 kPa



1.25) A thermodynamic cycle involves the following four processes. Draw the cycle on a *P-T* diagram.

(a) An isobaric heating from 500 K and 400 kPa to a temperature of 700 K
(b) An isothermal compression to a pressure of 800 kPa
(c) An isobaric cooling to a temperature of 500 K
(d) An appropriate isothermal expansion

Solution:



1.26) The melting point of lead at atmospheric pressure is 601 K. Determine this temperature in °C, °F, and R.

Given: T (K) = 601 K
Solution:

T (°C) = T (K) – 273 = **328°C**
T (°F) = 9/5 T (°C) + 32 = **622°F**
T (R) = 9/5 T(K) = **1082 R**

1.27) The melting point of gold at atmospheric pressure is 2405 R. Determine this temperature in °C, °F, and K.

Given: T(R) = 2405 R
Solution:

T (K) = 5/9 T(R) = **1336 K**
T (°C) = T(K) -273 **= 1063°C**
T(°F) = T(R) – 460 = **1945°F**

1.28) At a pressure of 5.1 atm, carbon dioxide will condense into a liquid at -57°C. Determine this temperature in °F, K and R.

Given: T(°C) = -57°C
Solution:

T (K) = T(°C) + 273 = **216 K**
T(R) = 9/5 T(K) = **389 R**
T(°F) = T(R) – 460 = **-71°F**
1.23 The “normal” temperature for a human being is 98.6°F. Determine this temperature in °C, K, and R.

1.29) The “normal” temperature for a human being is 98.6°F. Determine this temperature in °C, K, and R.

Given: T(°F) = 98.6°F
Solution:

T(°C) = 5/9 [T(°F) – 32] = **37°C**
T(K) = T(°C) + 273 = **310 K**
T(R) = 9/5 T(K) = **558 R**

1.30) The boiling point of ammonia at atmospheric pressure is 239.7 K. Determine this temperature in °C, °F, and R.

Given: T(K) = 239.7 K
Solution:

T (°C) = T (K) – 273 = **-33.3°C**
T (°F) = 9/5 T (°C) + 32 = **-27.9°F**
T (R) = 9/5 T(K) = **431.5 R**

1.31) The melting point of aluminum at atmospheric pressure is 1220°F. Determine this temperature in °C, K, and R.

Given: T(°F) = 1220°F
Solution:

T(°C) = 5/9 [T(°F) – 32] = **660°C**
T(K) = T(°C) + 273 = **933 K**
T(R) = 9/5 T(K) = **1679 R**

1.32) At atmospheric pressure, the boiling point of methanol is 337.7 K and the boiling point of ethanol is 351.5 K. Convert both of these temperatures to degrees Celsius, and determine the difference in these temperatures in both K and °C.

Given: $T_{meth}(K) = 337.7$ K; $T_{eth}(K) = 351.5$ K
Solution:
$T\ (^oC) = T\ (K) - 273$

$T_{meth}(^oC) =$ **64.7°C** $T_{eth}(^oC) =$ **78.5°C**

For $\Delta T = T_{eth} - T_{meth}$

ΔT (K) = **13.8 K**
ΔT (°C) = **13.8 °C**

1.33) At atmospheric pressure, the melting point of pure platinum is 2045 K, and the melting point of silver is 1235 K. Convert both of these temperatures to degrees Celsius, and determine the difference in these temperatures in both K and °C.

Given: $T_{Pt}(K) = 2045$ K; $T_{Ag}(K) = 1235$ K
Solution:

Platinum: $T_{Pt}(^oC) = T_{Pt}(K) - 273 =$ **1772°C**
Silver: $T_{Ag}(^oC) = T_{Ag}(K) - 273 =$ **962°C**
Differences in temperature: $\Delta T = 2045\ K - 1235\ K =$ **810 K**
$\Delta T = 1772^oC - 962^oC$ **= 810°C**

1.34) You wish to drop an ice cube into a cup of hot water to cool the water. The temperature of the ice cube is -10°C, and the water temperature is 92°C. Convert both of these temperatures to Kelvin, and determine the difference between the temperatures in both K and °C.

Given: $T_{ice}\ (^oC) = -10^oC$; $T_w\ (^oC) = 92^oC$
Solution:

$T_{ice}(K) = T_{ice}(^oC) + 273 =$ **263 K**
$T_w(K) = T_w(^oC) + 273 =$ **365 K**
ΔT (K) = 365 K – 263 K = **102 K**
ΔT (°C) = 92 °C – (-10°C) = **102 °C**

1.35) Oxygen, O_2, has a molecular mass of 32 kg/kmole. How many moles does 17 kg of O_2 represent?

Given: M = 32 kg/kmole; m = 17 kg
Solution:
n = m/M = **0.531 kmole**

1.36) You determine that 1.2 kmoles of a substance has a mass of 14.4 kg. Determine the molecular mass of the substance.

Given: n = 1.2 kmoles; m = 14.4 kg
Solution:
M = m/n = **12 kg/kmole**

1.37) You are asked if you would like to have a box which contains 3.5 kmole of gold. The only condition of the deal is that you must carry the box away using only your own strength. What is the mass of the gold in the box if the molecular mass of the gold is 197 kg/kmole? Do you think you will be able to accept this deal?

Given: n = 3.5 kmole; M = 197 kg/kmole
Solution:
m = Mn = **690 kg**
Even with the adrenaline that is bound to be present with the thought of getting all this gold, it is unlikely that one can accept the deal as it is too heavy to carry.

1.38) Suppose that one kilomole of any gaseous substance at a given temperature and pressure occupies a volume of 24 m^3. The density of a particular gas at these conditions is 1.28 kg/m^3. How much mass of the gas is present if you have a 2.0-m^3 container full of the gas at the given temperature and pressure, and what is the molecular mass of the gas?

Given: n = 1 kmole --- $\cancel{V} = 24\ m^3$; $\rho = 1.28\ kg/m^3$; $\cancel{V} = 2.0\ m^3$
Solution: The actual volume is 2/24 = 0.08333 of what is occupied by 1 kmole, so the number of moles at this volume is n = 0.08333 kmoles
$m = \rho\cancel{V} = (1.28\ kg/m^3)(2.0\ m^3)$ = **2.56 kg**
M = m/n = 30.72 kg/kmole

1.39) Burning a hydrocarbon fuel will convert the carbon in the fuel to carbon dioxide. For every kmole of carbon to be burned, you need 1 kmole of oxygen (O_2). This produces 1 kmole of CO_2. If you originally have 2 kg of carbon to be burned, what is the mass of the CO_2 that will be produced? The molecular mass of carbon is 12 kg/kmole, of oxygen is 32 kg/kmole, and of CO_2 is 44 kg/kmole.
Given: m_C = 2 kg; M_c = 12 kg/kmole; M_{CO2} = 44 kg/kmole

Solution:
The number of moles of Carbon is $n_C = m_c/M_c = 0.1667$ kmole
So, 0.1667 kmole of CO_2 will be produced. This has a mass of
$m_{CO2} = M_{CO2}\, n_{CO2}$ = (44 kg/kmole)(0.1667 kmole) **= 7.33 kg**

1.40) A rock at sea-level on Earth (where $g = 9.81$ m/s^2) has a mass of 25 kg. What is the weight of the rock in Newtons?

Given: m = 25 kg; g = 9.81 m/s^2
Solution:
W = mg = (25 kg)(9.81 m/s^2) = 245 kg-m/s^2 = **245 N**

1.41) On a distant planet, the acceleration due to gravity is 6.84 m/s^2. The weight of an object on that planet is 542 N. What is the mass of the object? If that object is moved to earth, where g = 9.81 m/s^2, what is the weight of the object?

Given: g_p = 6.84 m/s^2; W_p = 542 N; g_e = 9.81 m/s^2
Solution:
$m = W_p/g_p$ = (542 N) / (6.84 m/s^2) = **79.2 kg**
$W_e = mg_e$ = (79.2 kg)(9.81 m/s^2) = **777 N**

1.42) How much force is needed to accelerate a ball with a mass of 0.5 kg at a rate of 25 m/s^2?

Given: m = 0.5 kg; a = 25 m/s^2
Solution:
F = ma = (0.5 kg)(25 m/s^2) **= 12.5 N**

1.43) How much force is needed to accelerate a block with a mass of 1.59 lbm at a rate of 35 ft/s^2?

Given: m = 1.59 lbm; a = 35 ft/s^2
Solution:
$F = ma/g_c$ = (1.59 lbm)(35 ft/s^2) / (32.174 lbm-ft/lbf-s^2) = **1.73 lbf**

1.44) An object has a mass of 145 lbm. This object is sent into space, and is placed onto the surface of a planet where the acceleration due to gravity is 25 ft/s^2. What is the weight of the object in lbf on the other planet?

Given: m = 145 lbm; g_p =25 ft/s^2
Solution:

$W_p = mg_p/g_c$ = (145 lbm)(25 ft/s^2)/ (32.174 lbm-ft/lbf-s^2) = **113 lbf**

1.45) The acceleration due to gravity on Mars is 12.17 ft/s^2. At sea-level on the earth, an astronaut can lift an object that weighs 125 lbf. What is the mass of an object that the astronaut could lift on Mars?

Given: g_m = 12.17 ft/s^2; W_e = 125 lbf;
Assume: g_e = 32.174 ft/s^2
Solution:
Assume that the astronaut can continue to lift a weight equal to 125 lbf on Mars:
$m = W_e g_c/g_m$ = (125 lbf) (32.174 lbm-ft/lbf-s^2)/(12.17 ft/s^2) = **330 lbm**

1.46) A club applies a force of 12 lbf to a rubber ball which has a mass of 1.5 lbm. What is the acceleration experienced by the ball as it encounters the force?

Given: F = 12 lbf; m = 1.5 lbm
Solution:
$a = Fg_c/m$ = (12 lbf) (32.174 lbm-ft/lbf-s^2) / 1.5 lbm = **257 ft/s^2**

1.47) What force is required to accelerate a 5.0-lbm rock at a rate of 35 ft/s^2?

Given: a = 35ft/s^2; m = 5.0 lbm
Solution:
$F = ma/g_c$ = (5.0 lbm)(35 ft/s^2)/(32.174 lbm-ft/lbf-s^2)= **5.44 lbf**

1.48) The specific volume of steam at 500°C and 500 kPa is 0.7109 m^3/kg. You have a container whose volume is 0.57 m^3 which is full of the steam at 500°C and 500 kPa. Determine the mass of the steam in the container.

Given: v = 0.7109 m^3/kg; $\cancel{V}$ = 0.57 m^3
Solution: m = $\cancel{V}$/v = (0.57 m^3) / (0.7109 m^3/kg) = **0.802 kg**

1.49) A solid block of unknown composition has dimensions of 0.5 m in length, 0.25 m in width, and 0.1 m in height. The weight of the block at sea-level (g = 9.81 m/s^2) is 45 N. Determine the specific volume of the block.

Given: l = 0.5 m; w = 0.25 m; h = 0.1 m; W = 45 N; g = 9.81 m/s^2
Solution:

V = lwh = 0.0125 m^3
m = W/g = 4.587 kg
v = V/m = 0.00273 m^3/kg

(Note this is a density of 367 kg/m^3.)

1.50) A mixture of liquid water and water vapor occupies a cylindrical tube whose diameter is 0.05 m and whose length is 0.75 m. If the specific volume of the water is 0.00535 m^3/kg, determine the mass of the water present.

Given: $D = 0.05$ m; $l = 0.75$ m; $v = 0.00535\ m^3/kg$
Solution:

$V = (\pi D^2/4)l = 0.001473\ m^3$
$m = V/v =$ **0.275 kg**

1.51) The density of several metals are as follows: lead: 11,340 kg/m^3; tin: 7310 kg/m^3; aluminum: 2702 kg/m^3. You are given a small box (0.1 m x 0.1 m x 0.075 m) and are told that it is filled with one of these metals. Unable to open the box and unable to read the label on the box, you decide to weigh the box to determine the metal inside. You find that the weight of the box is 53.8 N. Determine the density and specific volume of the box, and choose the likely metal inside.

Given: $l = w = 0.1$ m; $h = 0.075$ m; $W = 53.8$ N
Assume: $g = 9.81\ m/s^2$
Solution:

$V = lwh = 0.00075\ m^3$
$m = W/g = 5.484$ kg
$v = V/m =$ **0.000138 m^3/kg**
$\rho = 1/v =$ **7,310 kg/m^3**
The metal is likely **tin**.

1.52) A person with a mass of 81 kg stands on a small platform whose base is 0.25 m x 0.25 m. Determine the pressure exerted on the ground below the platform by the person.

Given: $m = 81$ kg; $l = 0.25$ m; $w = 0.25$ m
Assume: $g = 9.81\ m/s^2$
Solution:

$A = lw = 0.0625\ m^2$
$F = W = mg = 794.6$ N
$P = F/A = 12{,}710$ Pa = **12.7 kPa**
1.53) A wall of area 2.5 m^2 is hit by a gust of wind. The force exerted by the wind upon the wall is 590 kN. Determine the pressure exerted by the wind on the wall.

Given: $A = 2.5\ m^2$; $F = 590$ kN

Solution:

$P = F/A = (590 \text{ kN})/(2.5 \text{ m}^2) =$ **236 kPa**

1.54) A press applies a pressure of 800 kPa uniformly over an area of 0.025 m^2. What is the total force applied by the press?

Given: $P = 800$ kPa; $A = 0.025 \text{ m}^2$
Solution: $F = PA = (800 \text{ kPa})(0.025 \text{ m}^2) = (800 \text{ kN/m}^2)(0.025 \text{ m}^2) =$ **20 kN**

1.55) A manometer is used to determine the pressure difference between the atmosphere and a tank of liquid. The fluid used in the manometer is water, with a density of 1000 kg/m^3. The manometer is located at sea-level where $g = 9.81 \text{ m/s}^2$. The difference in height between the liquid in the two legs of the manometer is 0.25 m. Determine the pressure difference.

Given: $\rho = 1{,}000 \text{ kg/m}^3$; $g = 9.81 \text{ m/s}^2$; $L = 0.25$ m
Solution:

$\Delta P = \rho g L = 2453 \text{ N/m}^2 =$ **2.45 kPa**

1.56) A mercury ($\rho = 13{,}500 \text{ kg/m}^3$) manometer is used to measure the pressure difference between two tanks containing fluids. The difference in height of the mercury in the two legs is 10 cm. Determine the difference in pressure between the tanks.

Given: $\rho = 13{,}500 \text{ kg/m}^3$; $L = 10 \text{ cm} = 0.10$ m
Assume: $g = 9.81 \text{ m/s}^2$
Solution:
$\Delta P = \rho g L = 13{,}240 \text{ N/m}^2 =$ **13.2 kPa**

1.57) You choose to use a mercury ($\rho = 13{,}500 \text{ kg/m}^3$) manometer to check the accuracy of a pressure gage on a compressed nitrogen gas tank. The manometer is set up between the tank and the atmosphere, and the height difference for the mercury in the two legs is 1.52 m. The pressure gage to be checked reads a pressure of 275 kPa for the gage pressure of the tank. Is the pressure gage accurate?

Given: $\rho = 13{,}500 \text{ kg/m}^3$; $L = 1.52$ m; $P_g = 275$ kPa (measured)
Assume: $g = 9.81 \text{ m/s}^2$
Solution:

$\Delta P = \rho g L = 201{,}300 \text{ N/m}^2 =$ **201 kPa**
The pressure gage is not accurate.

1.58) Compressed gas tanks often have gage pressures of at least 1 MPa. Suppose you wished to use a manometer to measure the gage pressure of a compressed air tank whose pressure was at least 1 MPa. The manometer would be set up between the tank and the atmosphere. What is the minimum length of tube needed for such a measurement if the liquid in the manometer is (a) mercury (ρ = 13,500 kg/m^3), (b) water (ρ = 1000 kg/m^3), and (c) engine oil (ρ = 880 kg/m^3)? Do these seem to be practical devices for such a measurement?

Given: P_g = 1 MPa = 1,000,000 Pa
Assume: g = 9.81 m/s^2
Solution:

(a) Mercury: ρ = 13,500 kg/m^3
$L = P_g / \rho g$ = (1,000,000 N/m^2)/[(13,500 kg/m^3)(9.81 m/s^2) = **7.55 m**

(b) Water: ρ = 1,000 kg/m^3
$L = P_g / \rho g$ = **102 m**

(c) Engine Oil: ρ = 880 kg/m^3
$L = P_g / \rho g$ = **116 m**

While none of the devices are particularly practical for this application, the mercury manometer could be made to work in a large laboratory or factory space.

1.59) A manometer using a liquid with a density of 625 lbm/ft^3 is set up to measure the pressure difference between two locations in a flow system. The height of the manometer liquid is 0.52 ft. What is the pressure difference between the two locations?

Given: ρ = 625 lbm/ft^3; L = 0.52 ft;
Assume: g = 32.174 ft/s^2
Solution:

$\Delta P = \rho g L/g_c$ = (625 lbm/ft^3)(32.174 ft/s^2)(0.52 ft)/(32.174(lbm-ft/lbf-s^2)) = **325 lbf/ft^2 = 2.26 psi**

1.60) The pressure gage on a tank of compressed nitrogen reads 785 kPa. A barometer is used to measure the local atmospheric pressure as 99 kPa. What is the absolute pressure in the tank?

Given: $P_g = 785$ kPa; $P_{atm} = 99$ kPa
Solution:

$P = P_g + P_{atm}$ **= 884 kPa**

1.61) The pressure gage on a tank of compressed air reads 120 psi. The local atmospheric pressure is measured as 14.5 psi. What is the absolute pressure in the tank?

Given: $P_g = 120$ psi; $P_{atm} = 14.5$ psi
Solution:

$P = P_g + P_{atm}$ **= 134.5 psi**

1.62) A pressure gage is used to measure the pressure of air inside a piston-cylinder device. The diameter of the cylinder is 8 cm. While the piston is at rest, the gage measures the pressure to be 40 kPa. A barometer measures the atmospheric pressure to be 100 kPa. A weight with a mass of 20 kg is placed on the top of the piston, and the piston moves until it reaches a new equilibrium point. What is the new gage pressure and the new absolute pressure of the air in the cylinder when this new equilibrium is reached?

Given: $D = 8$ cm $= 0.08$ m; $P_{g,i} = 40$ kPa; $P_{atm} = 100$ kPa; $m = 20$ kg
Assume: $g = 9.81$ m/s^2
Solution:

The new gage pressure will be the original gage pressure (caused by the weight of the piston) and the new gage pressure exerted by the 20 kg mass.
$P_{g,f} = P_{g,i} + (mg)/(\pi D^2/4) = 40$ kPa $+ 39{,}030$ Pa $=$ **79.0 kPa**
$P_f = P_{g,f} + P_{atm} =$ **179 kPa**

1.63) The absolute pressure of air in a piston-cylinder device is 220 kPa. The local atmospheric pressure is 99 kPa. If the acceleration due to gravity is 9.79 m/s^2, and if the diameter of the cylinder is 0.10 m, what is the mass of the piston?

Given: $P = 220$ kPa; $P_{atm} = 99$ kPa; $g = 9.79$ m/s^2; $D = 0.10$ m
Solution:

The gage pressure is
$P_g = P - P_{atm} = 121$ kPa $= 121{,}000$ Pa

The gage pressure is that which is exerted by the weight of the piston over the area of the piston:
$P_g = W/A = mg/(\pi D^2/4)$
$m = (\pi D^2/4)P_g / g =$ **96.9 kg**

1.64) Air is located in a piston-cylinder device. The diameter of the cylinder is 12 cm, the mass of the piston is 5 kg, and the acceleration due to gravity is 9.80 m/s^2. The local atmospheric pressure is 100.5 kPa. Determine the mass of a set of weights that needs to be added to the top of the piston so that the absolute pressure of the air in the cylinder is 250 kPa.

Given: D = 12 cm = 0.12 m; m = 5 kg; g = 9.80 m/s^2; P_{atm} = 100.5 kPa; P = 250 kPa
Solution:

The final gage pressure in the tank is $P_g = P - P_{atm}$ = 149.5 kPa = 149,500 Pa
The weight of the piston gives a gage pressure of
$P_g = W/A = mg/(\pi D^2/4) = 4{,}333$ Pa
The added weights must supply a $P_{g,w}$ = 149,500 Pa – 4,333 Pa = 145,167 Pa
To get this, we must add
$m = (\pi D^2/4)P_{g,w} / g =$ **168 kg**

1.65) A tank of liquid exerts a pressure of 300 kPa on a plug on the bottom of the tank. The local atmospheric pressure is 99 kPa. The diameter of the circular plug is 2.5 cm. What is the additional force that needs to be applied to the plug to keep the plug in place?

Given: P = 300 kPa; P_{atm} = 99 kPa; D = 2.5 cm = 0.025 m
Solution:

The local air pressure is pushing against the 300 kPa, so the remaining pressure that needs to be applied to keep the plug in place is P_g = 300 kPa – 99 kPa = 201 kPa
This pressure is applied over an area $A = \pi D^2/4 = 0.0004909$ m^2

So, the needed force is $F = P_gA =$ **98.7 N**

1.66) What is the absolute pressure of air located in a piston-cylinder device for a cylinder of diameter 0.5 ft, with a piston mass of 150 lbm, and local atmospheric pressure of 14.65 psi? The device is located at sea-level on earth.

Given: D = 1.5 ft; m = 150 lbm; P_{atm} = 14.65 psi
Assume: g = 32.174 ft/s^2
Solution:
$A = \pi D^2/4 = 0.1963$ ft^2

$F = W = mg/g_c = (150 \text{ lbm})(32.174 \text{ ft/s}^2) / (32.174 \text{ lbm-ft/lbf-s}^2) = 150 \text{ lbf}$
$P_g = F/A = (150 \text{ lbf}) / (0.1963 \text{ ft}^2) = 764.1 \text{ psf} = 5.31 \text{ psi}$

$P = P_g + P_{atm} =$ **19.96 psi**

1.67) Consider a piston-cylinder device initially at equilibrium with the air pressure inside the cylinder being 150 kPa. It is desired to raise the pressure of the air to 300 kPa by adding air to the cylinder, without changing the location of the piston. If the piston has a diameter of 8 cm, how much mass needs to be added to the piston to keep the piston in the same location with the higher pressure? Assume standard acceleration due to gravity at sea-level on the earth.

Given: $P_1 = 150$ kPa; $P_2 = 300$ kPa; $D = 8$ cm $= 0.08$ m
Assume: $g = 9.81 \text{ m/s}^2$
Solution:

Need to add 150 kPa of pressure in weight exerted by the mass of the piston:

$P = F/A = mg / A$

$A = \pi D^2 / 4 = 0.005027 \text{ m}^2$

$m = PA/g = (150{,}000 \text{ Pa})(0.005027 \text{ m}^2)/(9.81 \text{ m/s}^2) =$ **76.9 kg**

If you add 76.9 kg of mass to the piston, the piston will not move when the air is added to the cylinder to raise the pressure to 300 kPa.