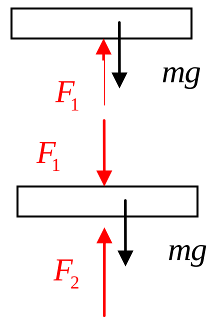
0-1-1 [US] Two thermodynamics books, each with a mass of 1 kg, are stacked one on top of another. Neglecting the presence of atmosphere, draw the free body diagram of the book at the bottom to determine the vertical force on its (a) top and (b) bottom faces in kN.

SOLUTION



(a) From the free body diagram of the book at the top, a vertical force balance produces:

$$F_1 = \frac{mg}{1000} \qquad \left[\mathrm{kg}\frac{\mathrm{m}}{\mathrm{s}^2}\frac{\mathrm{kN}}{\mathrm{N}} = \mathrm{kN} \right]$$

$$\Rightarrow F_1 = \frac{(1)(9.81)}{1000} = 0.00981\ \mathrm{kN}$$

(b) Using the free body diagram of the book at the bottom,

$$F_2 = F_1 + \frac{mg}{1000} \qquad [\mathrm{kN}]$$

$$\Rightarrow F_2 = 0.00981 + \frac{(1)(9.81)}{1000} = 0.01962\ \mathrm{kN}$$

0-1-2 [UA] Determine (a) the pressure felt on your palm to hold a textbook of mass 1 kg in equilibrium. Assume the distribution of pressure over the palm to be uniform and the area of contact to be 25 cm^2. (b) **What-if Scenario:** How would a change in atmospheric pressure affect your answer (0: No change; 1: increase; -1 decrease)?

SOLUTION

(a) $p = \dfrac{F}{A}$; $\left\lfloor \dfrac{\text{kN}}{\text{m}^2} = \text{kPa} \right\rfloor$

$$\Rightarrow p = \frac{mg}{1000A}; \qquad \Rightarrow p = \frac{(1)(9.81)}{(1000)(0.0025)};$$

$$\Rightarrow p = 3.924 \text{ kPa}$$

(b) A change in atmospheric pressure would not affect the answer because the net force created by a uniform pressure around any object is zero. Answer: 0

0-1-3 [UH] The lift-off mass of a Space Shuttle is 2 million kg. If the lift off thrust (the net force upward) is 10% greater than the minimum amount required for a lift-off, determine the acceleration.

SOLUTION

$$F_{\text{thrust}} - F_{\text{gravity}} = ma;$$

$$1.1\cancel{m}g - \cancel{m}g = \cancel{m}a; \quad \Rightarrow a = 0.1g;$$

$$\Rightarrow a = (0.1)(9.81);$$

$$\Rightarrow a = 0.981 \ \frac{\text{m}}{\text{s}^2}$$

0-1-4 [UF] A body weighs 0.05 kN on earth where g = 9.81 m/s^2. Determine its weight on (a) the moon, and (b) on mars with g = 1.67 m/s^2 and g = 3.92 m/s^2, respectively.

SOLUTION

$$m = \frac{w}{g}; \quad \Rightarrow m = \frac{0.05 \times 1000}{9.81}; \quad \Rightarrow m = 5.097 \text{ kg};$$

(a) On the moon: $w = \dfrac{(5.097)(1.67)}{1000}$; $\quad \Rightarrow w = 0.008512$ kN

(b) On Mars: $w = \dfrac{(5.097)(3.92)}{1000}$; $\quad \Rightarrow w = 0.01998$ kN

0-1-5 [UD] Calculate the weight of an object of mass 50 kg at the bottom and top of a mountain with (a) g = 9.8 m/s^2 and (b) g = 9.78 m/s^2 respectively.

SOLUTION

(a) $w = \dfrac{mg}{1000}$; $\quad \Rightarrow w = \dfrac{(50)(9.8)}{1000}$; $\quad \Rightarrow w = 0.49\text{ kN}$

(b) $w = \dfrac{(50)(9.78)}{1000}$; $\quad \Rightarrow w = 0.489\text{ kN}$

0-1-6 [UM] According to Newton's law of gravity, the value of g at a given location is inversely proportional to the square of the distance of the location from the center of the earth. Determine the weight of a textbook of mass 1 kg at (a) sea level and (b) in an airplane cruising at an altitude of 45,000 ft. Assume earth to be a sphere of diameter 12,756 km.

SOLUTION

(a) At sea level

$$w_0 = \frac{GmM}{R^2} = g_0 m;$$

$$\Rightarrow w_0 = (9.81)(1);$$

$$\Rightarrow w_0 = 9.81 \text{ N}$$

(b) At $h = 45{,}000 \text{ ft} \times 0.3048(10)^{-3} \dfrac{\text{km}}{\text{ft}} = 13.716 \text{ km}$

$$w = \frac{GmM}{(R+h)^2}; \quad \Rightarrow w = \frac{GmM}{R^2}\frac{R^2}{(R+h)^2}; \quad \Rightarrow w = g_0 \frac{R^2}{(R+h)^2} m; \quad \Rightarrow w = gm;$$

$$\Rightarrow g = \frac{\left(9.81 \dfrac{\text{m}}{\text{s}^2}\right)(6{,}378 \text{ km})^2}{(6{,}378 \text{ km} + 13.716 \text{ km})^2}; \quad \Rightarrow g = 9.76 \frac{\text{m}}{\text{s}^2};$$

$$\Rightarrow w = (9.767)(1);$$

$$\Rightarrow w = 9.76 \text{ N}$$

0-1-7 [UJ] The frictional force on a block of mass m_A resting on a table (see accompanying figure) is given as $F = \mu N$, where N is the normal reaction force from the table. Determine the maximum value for m_B that can be supported by friction. Assume the pulley to be frictionless.

SOLUTION

The maximum value of m_B that can be supported by the friction:

$$F_A = \frac{\mu m_A g}{1000}; \quad [\text{kN}]$$

$$F_B = \frac{m_B g}{1000}; \quad [\text{kN}]$$

$$F_A = F_B;$$

$$\Rightarrow \mu m_A \cancel{g} = m_B \cancel{g};$$

$$\Rightarrow m_B = \mu m_A$$

0-1-8 [UW] If the block A in problem 0-1-7 [UJ] sits on a wedge with an angle θ with the horizontal, how would the answer change?

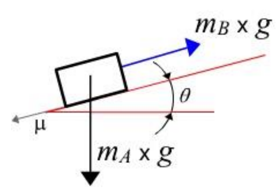
SOLUTION

The normal force on the block is: $N = \dfrac{m_A g \cos\theta}{1000}; \ \left[\text{kN}\right]$

A balance between the tension in the string and friction produces:

The normal force on t

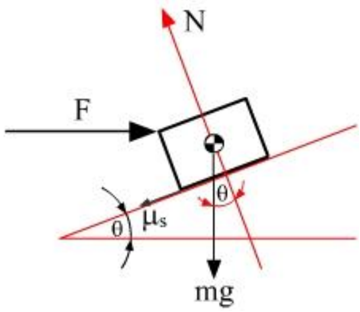
$$\frac{\mu m_A g \cos\theta}{1000} = \frac{m_B g}{1000};$$



$$\Rightarrow \mu m_A \cancel{g} \cos\theta = m_B \cancel{g};$$

$$\Rightarrow m_B = \mu m_A \cos\theta$$

0-1-9 [XR] A block with a mass of 10 kg is at rest on a plane inclined at 25° to the horizontal. If $\mu_s = 0.6$, determine the range of the horizontal push force F if the block is (a) about to slide down, and (b) about to slide up.



SOLUTION

(a) As the block is about to slide down, friction acts upward and a force balance along the slope yields:

$$F\cos\theta + \mu_s\left(mg\cos\theta + F\sin\theta\right) = \frac{mg\sin\theta}{1000};$$

$$\Rightarrow F\left(\cos\theta + \mu_s\sin\theta\right) = \frac{mg(\sin\theta - \mu_s\cos\theta)}{1000};$$

$$\Rightarrow F = \frac{mg(\sin\theta - \mu_s\cos\theta)}{1000\left(\cos\theta + \mu_s\sin\theta\right)};$$

$$\Rightarrow F = \frac{(10)(9.81)(\sin 25° - 0.6\cos 25°)}{(1000)\left(\cos 25° + 0.6\sin 25°\right)};$$

$$\Rightarrow F = -0.010248 \text{ kN}$$

The negative sign indicates that a slight pull force is necessary to overcome friction for the block to slide down.

(b) As the block is about to slide up, friction acts downward and a force balance along the slope yields:

$$F\cos\theta = \frac{\mu_s\left(mg\cos\theta + F\sin\theta\right) + mg\sin\theta}{1000};$$

$$\Rightarrow F\left(\cos\theta - \mu_s\sin\theta\right) = \frac{mg(\mu_s\cos\theta + \sin\theta)}{1000}; \quad \Rightarrow F = \frac{mg(\mu_s\cos\theta + \sin\theta)}{1000\left(\cos\theta - \mu_s\sin\theta\right)}$$

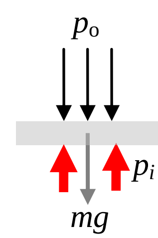
$$\Rightarrow F = \frac{(10)(9.81)(0.6\cos 25° + \sin 25°)}{(1000)\left(\cos 25° - 0.6\sin 25°\right)};$$

$$\Rightarrow F = 0.1452 \text{ kN}$$

0-1-10 [XO] A vertical piston cylinder device contains a gas at an unknown pressure. If the outside pressure is 100 kPa, determine (a) the pressure of the gas if the piston has an area of 0.2 m^2 and a mass of 20 kg. Assume g = 9.81 m/s^2. (b) **What-if Scenario:** What would the pressure be if the orientation of the device were changed and it were now upside down?

SOLUTION

(a) $$p_i A_{\text{piston}} = p_0 A_{\text{piston}} + \frac{m_{\text{piston}} g}{1000};$$ $$\left[\text{kPa}\cdot\text{m}^2 = \text{kg}\frac{\text{m}}{\text{s}^2}\frac{\text{kN}}{\text{N}} = \text{kN}\right]$$



$$\Rightarrow p_i = p_0 + \frac{m_{\text{piston}} g}{(1000)\, A_{\text{piston}}};$$ $$\left[\text{kPa} = \frac{\text{kN}}{\text{m}^2} = \text{kg}\frac{\text{m}}{\text{s}^2}\frac{\text{kN}}{\text{N}}\frac{1}{\text{m}^2}\right]$$

$$\Rightarrow p_i = 100 + \frac{(20)(9.81)}{(1000)(0.2)};$$

$$\Rightarrow p_i = 100.981 \text{ kPa}$$

(b) $$p_i A_{\text{piston}} + \frac{m_{\text{piston}} g}{1000} = p_0 A_{\text{piston}};$$ $$\left[\text{kPa}\cdot\text{m}^2 = \text{kg}\frac{\text{m}}{\text{s}^2}\frac{\text{kN}}{\text{N}} = \text{kN}\right]$$

$$\Rightarrow p_i = p_0 - \frac{m_{\text{piston}} g}{(1000)\, A_{\text{piston}}};$$

$$\Rightarrow p_i = 100 - \frac{(20)(9.81)}{(1000)(0.2)};$$

$$\Rightarrow p_i = 99.019 \text{ kPa}$$

0-1-11 [XB] Determine the mass of the weight necessary to increase the pressure of the liquid trapped inside a piston-cylinder device to 120 kPa. Assume the piston to be weightless with an area of 0.1 m^2, the outside pressure to be 100 kPa and g = 9.81 m/s^2.

SOLUTION

$$p_i A_{\text{piston}} = p_0 A_{\text{piston}} + \frac{m_w g}{1000}; \qquad \left\lfloor \text{kPa} \cdot \text{m}^2 = \text{kg} \frac{\text{m}}{\text{s}^2} \frac{\text{kN}}{\text{N}} = \text{kN} \right\rfloor$$

$$\Rightarrow p_i = p_0 + \frac{m_w g}{(1000) A_{\text{piston}}}; \quad [\text{kPa}]$$

$$\Rightarrow m_w = \frac{(p_i - p_0) A_{\text{piston}} (1000)}{g}; \quad [\text{kg}]$$

$$\Rightarrow m_w = \frac{(120 - 100)(0.1)(1000)}{9.81};$$

$$\Rightarrow m_w = 203.873 \text{ kg}$$

0-1-12 [XS] A mass of 100 kg is placed on the piston of a vertical piston-cylinder device containing nitrogen. The piston is weightless and has an area of 1 m^2. The outside pressure is 100 kPa. Determine (a) the pressure inside the cylinder. The mass placed on the piston is now doubled to 200 kg. Also, additional nitrogen is injected into the cylinder to double the mass of nitrogen. (b) Determine the pressure inside under these changed conditions. Assume temperature to remain unchanged at 300 K and R for nitrogen to be 0.296 kJ/kg-K.

SOLUTION

(a) A vertical force balance on the piston yields:

$$p_i A_{\text{piston}} = p_0 A_{\text{piston}} + \frac{m_w g}{1000}; \quad \left[\text{kPa}\cdot\text{m}^2 = \text{kg}\frac{\text{m}}{\text{s}^2}\frac{\text{kN}}{\text{N}} = \text{kN} \right]$$

$$\Rightarrow p_i = p_0 + \frac{m_w g}{(1000) A_{\text{piston}}}; \quad [\text{kPa}]$$

$$\Rightarrow p_i = 100 + \frac{(100)(9.81)}{(1000)(1)};$$

$$\Rightarrow p_i = 100.98 \text{ kPa}$$

(b) As the weight is doubled, the force balance on the piston yields:

$$p_i = \frac{(200)(9.81)}{(1)(1000)} + 100;$$

$$\Rightarrow p_i = 101.96 \text{ kPa}$$

Note the amount of nitrogen (or the identity of the gas) is not relevant.

0-1-13 [XN] A piston with a diameter of 50 cm and a thickness of 5 cm is made of a composite material with a density (ρ) of 4000 kg/m^3. (a) If the outside pressure is 101 kPa, determine the pressure inside the piston-cylinder assembly if the cylinder contains air. (b) **What-if Scenario:** What would the inside pressure be if the piston diameter were 100 cm instead? (c) Would the answers change if the cylinder contains liquid water instead? (1: yes; 2: no)

SOLUTION

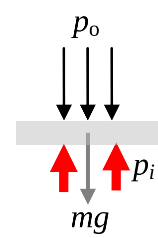
(a) $A = \dfrac{\pi d^2}{4}; \quad \Rightarrow A = (\pi)\dfrac{(0.5)^2}{4}; \quad \Rightarrow A = 0.1963 \text{ m}^2;$

$$m_{\text{piston}} = \rho A t; \quad [\text{kg}]$$

$$\Rightarrow m_{\text{piston}} = (4000)(\pi)\frac{(0.5)^2}{4}0.05; \quad \Rightarrow m_{\text{piston}} = 39.25 \text{ kg};$$

$$p_i = p_0 + \frac{m_{\text{piston}}\, g}{(1000)\, A_{\text{piston}}}; \quad [\text{kPa}]$$

$$\Rightarrow p_i = 101 + \frac{(39.25)(9.81)}{(1000)(0.1963)}; \quad \Rightarrow p_i = 102.96 \text{ kPa}$$



(b) $m_{\text{piston}} = (4000)(\pi)\dfrac{(1)^2}{4}(0.05); \quad \Rightarrow m_{\text{piston}} = 157 \text{ kg};$

$$p_i = p_0 + \frac{m_{\text{piston}}\, g}{(1000)\, A_{\text{piston}}};$$

$$\Rightarrow p_i = 101 + \frac{(157)(9.81)}{(1000)(0.7854)}; \quad \Rightarrow p_i = 102.96 \text{ kPa}$$

(c) No, the force balance on the piston does not depend on the identity of the fluids exerting pressures. Answer: 2

0-1-14 [XA] A piston-cylinder device contains 0.02 m^3 of hydrogen at 300 K. It has a diameter of 10 cm. The piston (assumed weightless) is pulled by a connecting rod perpendicular to the piston surface. If the outside conditions are 100 kPa and 300 K, (a) determine the pull force necessary in kN to create a pressure of 50 kPa inside. (b) The piston is now released; as it oscillates back and forth and finally comes to equilibrium, the temperature inside is measured as 600 K (reasons unknown). What is the pressure of hydrogen at equilibrium? (c) **What-if Scenario:** What would be the answer in part (a) if the gas were oxygen instead?

SOLUTION

(a) A vertical force balance on the piston yields:

$$F + p_i A = p_0 A; \quad [\text{kN}]$$

$$\Rightarrow F = (p_0 - p_i)A;$$

$$\Rightarrow F = (100-50)\left(\frac{\pi}{4}\right)(0.1^2); \qquad \Rightarrow F = 0.393 \text{ kN}$$

(b) With the external force absent, a new force balance on the piston after it comes to equilibrium yields:

$$p_i A = p_0 A; \quad [\text{kN}]$$

$$\Rightarrow p_i = p_0; \qquad \Rightarrow p_i = 100 \text{ kPa}$$

(c) The identity of the gas has nothing to do with the force balance. Therefore, the answer does not change.

F = 0.393 kN.

0-1-15 [XH] Air in the accompanying piston-cylinder device is in equilibrium at 200°C. If the mass of the hanging weight is 10 kg, atmospheric pressure is 100 kPa, and the piston diameter is 10 cm, (a) determine the pressure of air inside. Assume g = 9.81 m/s^2. (b)**What-if Scenario:** What would the pressure be if the gas were hydrogen instead? Molar mass of air is 29 kg/kmol and that of hydrogen is 2 kg/kmol. Neglect piston mass and friction.

SOLUTION

(a) A vertical force balance on the piston yields:

$$p_i A_p + \frac{mg}{1000} = p_0 A_p; \quad [\text{kN}]$$

$$\Rightarrow p_i = p_0 - \frac{mg}{A_p(1000)}; \quad [\text{kPa}]$$

$$\Rightarrow p_i = 100 - \frac{(10)(9.81)(4)}{(1000)(\pi)(0.1)^2}; \qquad \Rightarrow p_i = (100 - 12.49);$$

$$\Rightarrow p_{in} = 87.51 \text{ kPa}$$

(b) The force balance does not depend on the identity of the gas. Hence,

$$p_i = 87.51 \text{ kPa}$$

0-1-16 [XE] A vertical hydraulic cylinder has a piston with a diameter of 100 mm. If the ambient pressure is 100 kPa, determine the mass of the piston if the pressure inside is 1000 kPa.

SOLUTION

A vertical force balance on the piston yields:

$$p_i A_p = p_0 A_p + \frac{m_p g}{1000}; \qquad \left[\mathrm{kPa \cdot m^2 = kg \frac{m}{s^2} \frac{kN}{N} = kN} \right]$$

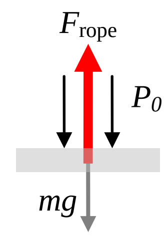
$$\Rightarrow m_p = \frac{(p_i - p_0) A_p (1000)}{g}; \qquad [\mathrm{kg}]$$

$$\Rightarrow m_p = \frac{(1000 - 100)(3.14)\left(\frac{0.1^2}{4}\right)(1000)}{(9.81)};$$

$$\Rightarrow m_p = 720.18 \text{ kg}$$

0-1-17 [XI] Determine the pull force necessary on the rope to reduce the pressure of the liquid trapped inside a piston cylinder device to 80 kPa. Assume the piston to be weightless with a diameter of 0.1 m, the outside pressure to be 100 kPa, and g = 9.81 m/s^2.

SOLUTION



A vertical force balance on the piston yields:

$$F + p_i A = p_0 A; \quad [\text{kN}]$$

$$\Rightarrow F = (p_0 - p_i) A;$$

$$\Rightarrow F = (100 - 80)\left(\frac{\pi}{4}\right)(0.1^2); \qquad \Rightarrow F = 0.157 \text{ kN}$$

0-1-18 [XL] A piston-cylinder device contains 0.17 m^3 of hydrogen at 450^oC. It has a diameter of 50 cm. The piston (assumed weightless) is pulled by a connecting rod perpendicular to the piston surface. If the outside conditions are 100 kPa, 25^oC, (a) determine the pull force necessary in kN to create a pressure of 60 kPa inside. (b) The piston is now released. It oscillates back and forth and finally comes to equilibrium. Determine the pressure at that state.

SOLUTION

(a) A vertical force balance on the piston yields:

$$F + p_i A = p_0 A; \quad [\text{kN}]$$

$$\Rightarrow F = (p_0 - p_i) A;$$

$$\Rightarrow F = (100 - 60)\left(\frac{\pi}{4}\right)(0.5^2); \qquad \Rightarrow F = 7.85 \text{ kN}$$

(b) With the external force absent, a new force balance on the piston after it comes to equilibrium yields:

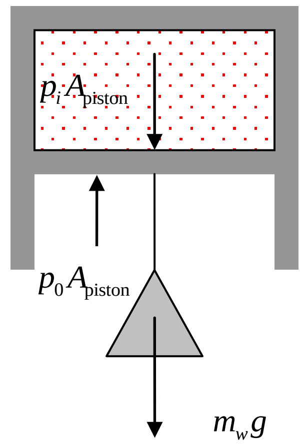
$$p_i A = p_0 A; \quad [\text{kN}]$$

$$\Rightarrow p_i = p_0; \qquad \Rightarrow p_i = 100 \text{ kPa}$$

0-1-19 [XG] A 5 cm diameter piston-cylinder device contains 0.04 kg of an ideal gas at equilibrium at 100 kPa, 300 K occupying a volume of 0.5 m^3. Determine (a) the gas density (ρ), and (b) the specific volume (v). (c) A weight is now hung from the piston (see figure) so that the piston moves down to a new equilibrium position. Assuming the piston to be weightless, determine the mass of the hanging weight necessary to reduce the gas pressure to 50 kPa. (Data supplied: g = 9.81 m/s^2; Outside pressure: 100 kPa).

.

SOLUTION:



(a) $\rho = \dfrac{m}{\cancel{V}}; \quad \Rightarrow \rho = \dfrac{.04}{.5}; \quad \Rightarrow \rho = 0.08 \ \dfrac{\text{kg}}{\text{m}^3}$

(b) $v = \dfrac{1}{\rho}; \quad \Rightarrow v = \dfrac{1}{0.08}; \quad \Rightarrow v = 12.5 \ \dfrac{\text{m}^3}{\text{kg}}$

(c) A vertical force balance on the piston produces:

$$p_i A_{\text{piston}} + \frac{m_w g}{1000} = p_0 A_{\text{piston}}; \quad \left\lfloor \text{kPa}\cdot\text{m}^2 = \text{kg}\frac{\text{m}}{\text{s}^2}\frac{\text{kN}}{\text{N}} = \text{kN} \right\rfloor$$

$$\Rightarrow m_w = \frac{(p_0 - p_i) A_{\text{piston}} (1000)}{g};$$

$$\Rightarrow m_w = \frac{(100-50)(1000)}{9.81}\pi\left(\frac{.05}{2}\right)^2;$$

$$\Rightarrow m = 10 \text{ kg}$$

0-1-20 [XZ] In problem 0-1-19 [XG], the gas is now cooled so that the piston moves upward towards the original position with the weight still hanging. Determine the pressure when the gas shrinks to its original volume of 0.5 m^3.

SOLUTION

With the force balance on the piston remaining unchanged, so must be the pressure inside. Answer: 50 kPa.