

Problem 9E

THE IDEAL GAS LAW

PROBLEM

A hot-air balloon named *Double Eagle V* traveled a record distance of more than 8000 km from Japan to California in 1981. The volume of the balloon was $1.13 \times 10^4 \text{ m}^3$. If the balloon contained 2.84×10^{29} gas particles that had an average temperature of 355 K, what was the absolute pressure of the gas in the balloon?

SOLUTION

1. DEFINE

Given:

$$V = 1.13 \times 10^4 \text{ m}^3$$

$$N = 2.84 \times 10^{29} \text{ particles}$$

$$T = 355 \text{ K}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

Unknown: $P = ?$

2. PLAN

Choose the equation(s) or situation: To find the pressure of the gas, use the ideal gas law.

$$PV = Nk_B T$$

Rearrange the equation(s) to isolate the unknown(s):

$$P = \frac{Nk_B T}{V}$$

3. CALCULATE

Substitute the values into the equation(s) and solve:

$$P = \frac{(2.84 \times 10^{29} \text{ particles})(1.38 \times 10^{-23} \text{ J/K})(355 \text{ K})}{1.13 \times 10^4 \text{ m}^3}$$

$$P = \boxed{1.23 \times 10^5 \text{ Pa}}$$

4. EVALUATE

The pressure inside the balloon is about 20 percent greater than standard air pressure. This pressure corresponds to the higher temperature of the air in the balloon. The hot air's temperature is also nearly 20 percent greater than 300 K.

ADDITIONAL PRACTICE

- The official altitude record for a balloon was set in 1961 by two American officers piloting a high-altitude helium balloon with a volume of $3.4 \times 10^5 \text{ m}^3$. Assume that the temperature of the gas was 280 K. If the balloon contained 1.4×10^{30} atoms of helium, find the absolute pressure in the balloon at the maximum altitude of 35 km.
- The estimated number of locusts that made up a swarm that infested Nebraska in 1874 was 1.2×10^{13} . This number was about 7000 times the total human population of Earth back then and about 2000 times the total human population today. It is, however, only a few billionths of the number of molecules in a liter of gas. If a container with a volume of $1.0 \times 10^{-3} \text{ m}^3$

is filled with 1.2×10^{13} gas molecules maintained at a temperature of 300.0 K, what is the pressure of the gas in the container?

- 3.** In terms of volume, the largest pyramid in the world is not in Egypt but in Mexico. The Pyramid of the Sun at Teotihuacan has a volume of $3.3 \times 10^6 \text{ m}^3$. If you fill a balloon to this same volume with 1.5×10^{32} molecules of nitrogen at a temperature of 360 K, what will the absolute pressure of the gas be?
- 4.** A snow palace more than 30 m high was built in Japan in 1994. Suppose a container with the same volume as this snow palace is filled with 1.00×10^{27} molecules. If the temperature of the gas is $2.70 \times 10^2 \text{ K}$ and the gas pressure is 36.2 Pa, what is the volume of the gas?
- 5.** Suppose the volume of a balloon decreases so that the temperature of the balloon decreases from 280 K to 240 K and its pressure drops from $1.6 \times 10^4 \text{ Pa}$ to $1.7 \times 10^4 \text{ Pa}$. What is the new volume of the gas?
- 6.** The longest navigable tunnel in the world was built in France. Suppose the entire tunnel, which has a cross-sectional area of $2.50 \times 10^2 \text{ m}^2$, is filled with air at a temperature of $3.00 \times 10^2 \text{ K}$ and a pressure of 101 kPa. If the tunnel contains 4.34×10^{31} molecules, what is the volume and length of the tunnel?
- 7.** A balloon is filled with $7.36 \times 10^4 \text{ m}^3$ of hot air. If the pressure inside the balloon is $1.00 \times 10^5 \text{ Pa}$ and there are 1.63×10^{30} particles of air inside, what is the average temperature of the air inside the balloon?
- 8.** In 1993, a group of American researchers drilled a 3053 m shaft in the ice sheet of Greenland. Suppose the cross-sectional area of the shaft is 0.040 m^2 . If the air in the shaft consists of 3.6×10^{27} molecules at an average pressure of 105 kPa, what is the air's average temperature?
- 9.** The cylinder of the largest steam engine had a radius of 1.82 m. Suppose the length of the cylinder is six times the radius. Steam at a pressure of $2.50 \times 10^6 \text{ Pa}$ and a temperature of 495 K enters the cylinder when the piston has reduced the volume in the cylinder to 3.00 m^3 . The piston is then pushed outward until the volume of the steam in the cylinder is 57.0 m^3 . If the pressure of the steam after expansion is $1.01 \times 10^5 \text{ Pa}$, what is the temperature of the steam?