And the speed of sound in gasoline is approximately,

$$a_{1\,atm} = [(8.0)(901)(101350\text{ Pa})/(680\text{ kg/m}^3)]^{1/2} \approx \mathbf{1040\ \frac{m}{s}} \quad \textit{Ans.}\text{ (a)}$$

1.78 Sir Isaac Newton measured sound speed by timing the difference between seeing a cannon's puff of smoke and hearing its boom. If the cannon is on a mountain 5.2 miles away, estimate the air temperature in °C if the time difference is (a) 24.2 s; (b) 25.1 s.

Solution: Cannon booms are finite (shock) waves and travel slightly faster than sound waves, but what the heck, assume it's close enough to sound speed:

(a) $a \approx \frac{\Delta x}{\Delta t} = \frac{5.2(5280)(0.3048)}{24.2} = 345.8\ \frac{m}{s} = \sqrt{1.4(287)T}, \quad T \approx 298\text{ K} \approx \mathbf{25°C} \quad \textit{Ans.}\text{ (a)}$

(b) $a \approx \frac{\Delta x}{\Delta t} = \frac{5.2(5280)(0.3048)}{25.1} = 333.4\ \frac{m}{s} = \sqrt{1.4(287)T}, \quad T \approx 277\text{ K} \approx \mathbf{4°C} \quad \textit{Ans.}\text{ (b)}$

1.79 Even a tiny amount of dissolved gas can drastically change the speed of sound of a gas-liquid mixture. By estimating the pressure-volume change of the mixture, Olson [40] gives the following approximate formula:

$$a_{mixture} = \sqrt{\frac{p_g K_l}{[x\rho_g + (1-x)\rho_l][xK_l + (1-x)p_g]}}$$

where x is the volume fraction of gas, K is the bulk modulus, and subscripts ℓ and g denote the liquid and gas, respectively. (a) Show that the formula is dimensionally homogeneous. (b) For the special case of air bubbles (density 1.7 kg/m^3 and pressure 150 kPa) in water (density 998 kg/m^3 and bulk modulus 2.2 GPa), plot the mixture speed of sound in the range $0 \le x \le 0.002$ and discuss.

Solution: (a) Since x is dimensionless and K dimensions cancel between the numerator and denominator, the remaining dimensions are pressure divided by density:

$$\{a_{mixture}\} = [\{p\}/\{\rho\}]^{1/2} = [(M/LT^2)/(M/L^3)]^{1/2} = [L^2/T^2]^{1/2}$$
$$= \mathbf{L/T} \quad \textit{Yes, homogeneous} \quad \textit{Ans.}\text{ (a)}$$

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