Making a Galileo Thermometer

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1 Appendix

1.1 Volumetric Thermal Expansion Coefficient

Take the volumetric thermal expansion coefficient (β) definition:

$$\beta = \frac{1}{v}\frac{dv}{dT}$$

Then we can assume beta is constant in a small temperature range (about 10°C) because we know the beta value for every 10 degrees of water.

$$\frac{dv}{v} = \beta dT$$

Find the integral:

$$\int_{v_0}^{v} \frac{dv'}{v} = \int_{T_0}^{T} \beta \, dT'$$

$$\ln \frac{v}{v_0} = \beta(T - T_0)$$

Solve:

$$\frac{v}{v_0} = e^{\beta \Delta T}$$

Substitute into density equation:

$$\rho(T) = \frac{m}{v(T)}$$

$$\rho(T) = \frac{m}{v_0 e^{\beta \Delta T}}$$

Now we have an equation governing the density change of water when temperature changes.

1.2 Archimedes' Principle and Neutral Buoyancy

The buoyant force acting on a vial immersed in a fluid is given by

$$F_b = \rho_{\text{fluid}}(T)\, g\, V_{\text{vial}},$$

where $\rho_{\text{fluid}}(T)$ is the temperature-dependent density of the surrounding fluid, g is gravitational acceleration, and V_{vial} is the volume of fluid displaced by the vial. The gravitational force acting on the vial is

$$F_g = m_{\text{vial}} g.$$

A vial is neutrally buoyant when the net force on it is zero:

$$F_b = F_g.$$

Substituting expressions for the forces gives

$$\rho_{\text{fluid}}(T)\, g\, V_{\text{vial}} = m_{\text{vial}} g.$$

Canceling g and rearranging yields

$$\rho_{\text{fluid}}(T) = \frac{m_{\text{vial}}}{V_{\text{vial}}} = \rho_{\text{vial}}.$$

Thus, neutral buoyancy occurs when the density of the vial equals the density of the surrounding fluid, which forms the basis for temperature measurement in a Galileo thermometer.

This model neglects surface tension forces at the vial–fluid interface, which can provide an additional upward force and lead to deviations from the predicted neutral buoyancy condition for small vials, especially at high temperatures.