Making a Galileo Thermometer

Fall 2025 Introduction to Thermal-Fluid Systems - Ellie Kung

Background

Introduction

A Galileo thermometer measures temperature based on the temperature dependence of fluid density. As temperature increases, the density of a liquid decreases due to thermal expansion, while the mass and volume of sealed solid objects immersed in the liquid remain approximately constant. This behavior is governed by

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

where ρ is density, m is mass, and v is volume. For liquids, volume increases with temperature, causing density to decrease. This change in density enables buoyancy-based temperature measurement. (see appendix).

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

A Galileo thermometer consists of sealed vials with slightly different densities suspended in a surrounding liquid. If a vial's density is greater than the surrounding fluid, it sinks; if it is less, it floats. The temperature of the system lies between the highest sinking vial and the lowest floating vial.

Range and Calibration

The target operating range for this thermometer was 0–100 °C. Ice water and boiling water were selected as calibration standards because they provide convenient, well-defined reference temperatures. A commercial meat thermometer was used as an independent calibration reference, with an estimated uncertainty of ±2 °C (measured at ice and boiling water).

System Diagram

A real galileo thermometer is a closed, multiphase thermal-fluid system. The primary components are: sealed vials , a surrounding water column (a liquid system with temperature-dependent density), and a thermal boundary between the tube and the environment. In order to simplify my model, I removed the thermal boundaries, making the tube the environment I was measuring.

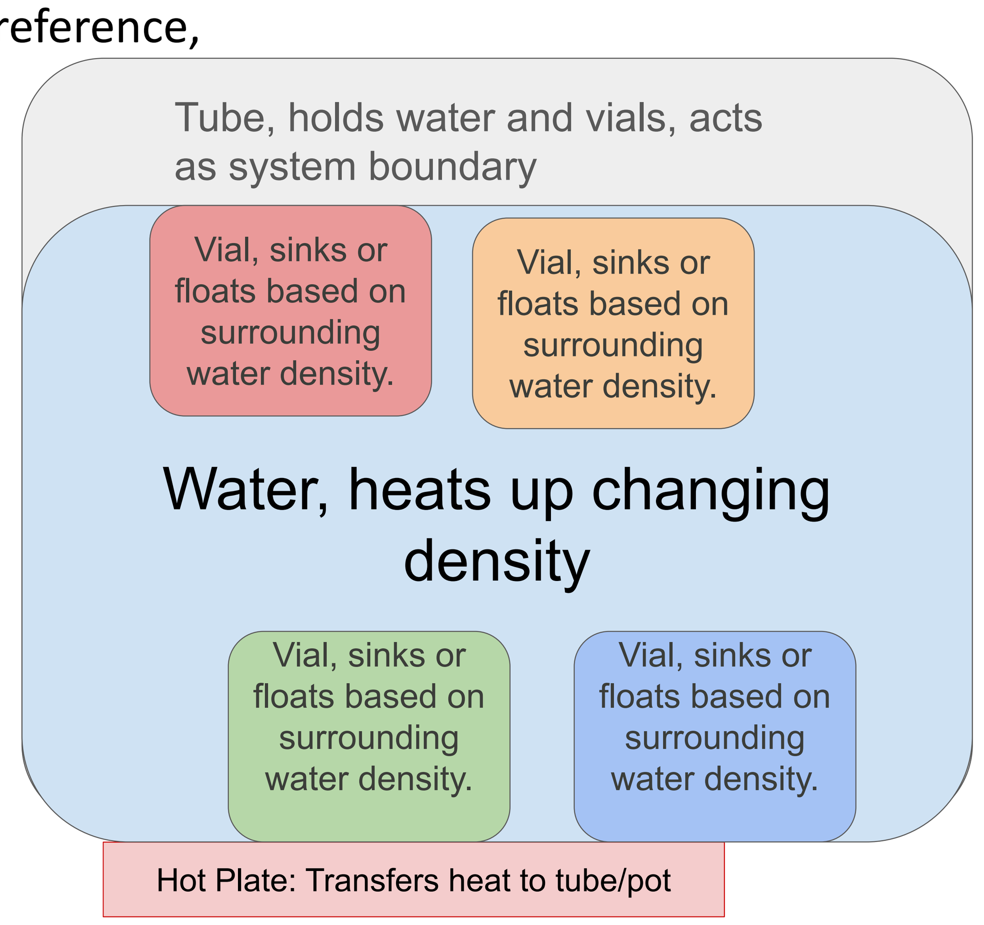

Fig 1: System Diagram of the Galileo thermometer system, consisting of sealed vials suspended in a tube filled with water.

Methodology

Model

The thermometer model is based on Archimedes' principle:

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

where F_b is the buoyant force, $\rho_{fluid}(T)$ is the temperature-dependent density of water, g is gravitational acceleration, and V_{vial} is the vial volume. A vial is neutrally buoyant when the buoyant force equals the gravitational force on the vial, corresponding to $\rho(T)_{vial} = \rho(T)_{fluid}$. (see appendix).

The model assumes:

- Sealed vials have constant mass and volume
- Water density depends only on temperature
- The system is in static equilibrium
- Surface tension and viscous effects are negligible

Experiment

An initial analytical model used predicted water density values to predict the vial masses required for neutral buoyancy at specific temperatures. We decided since the masses were so similar, we would do increments of 20 degrees, meaning our thermometer would only be accurate to ±10℃. We measured two vials, one for ice water and one for 20℃. We put both vials in room temperature water (22.3℃) but they both sank.

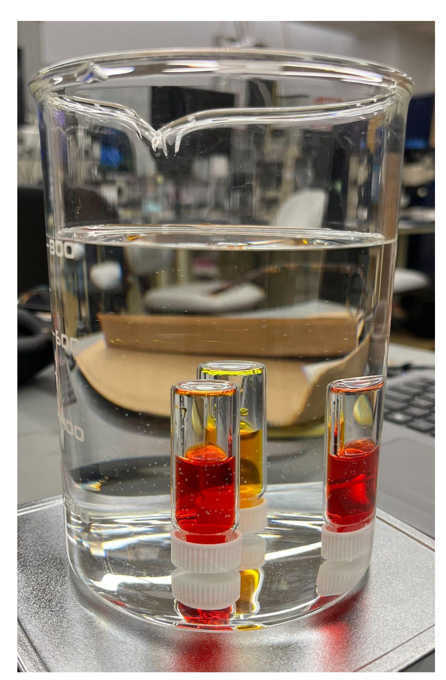

Fig 2: Predicted vial masses sinking at room temperature

When the predicted measured masses failed to match the correct configuration, the approach was iterated. Vial volume was increased so there could be more difference in mass and vial masses were adjusted by hand at known temperatures to identify neutral buoyancy conditions.

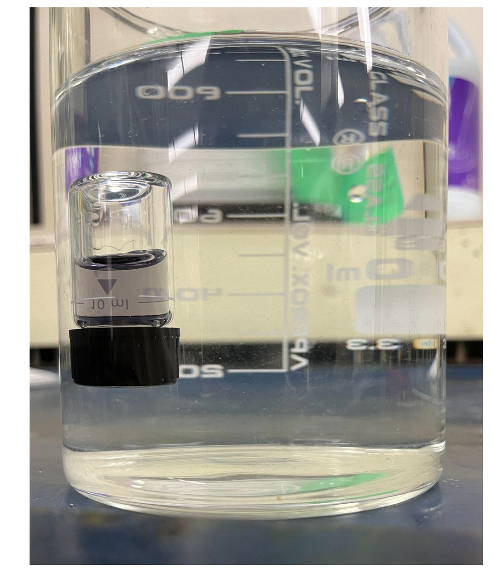

Fig 3: Achieving neutral density with a larger vial in room temperature water

I then compared these neutral buoyancy conditions to my model.

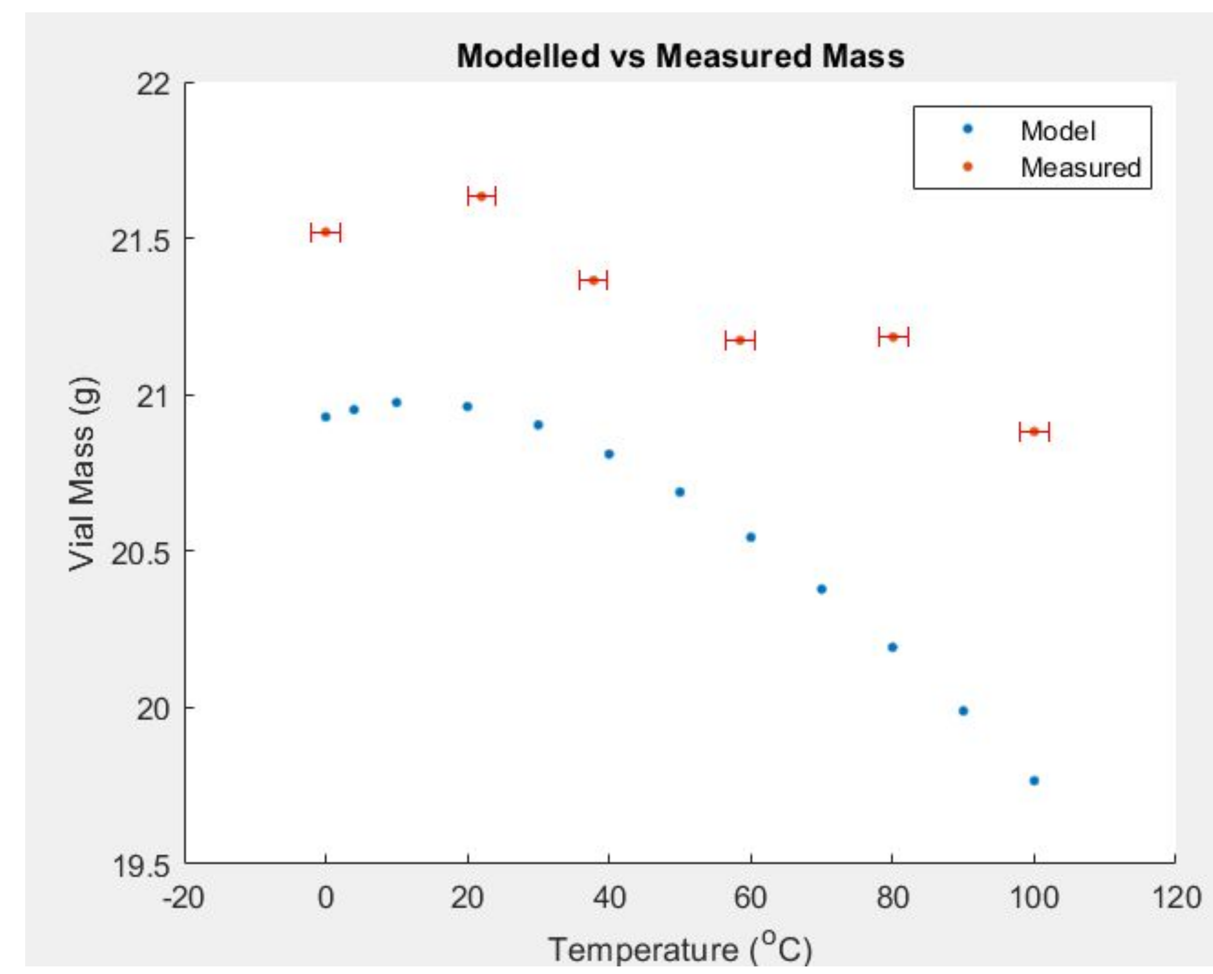

Fig 4: The modelled vial mass peaks at 4°C and steadily declines. This relationship is directly correlated with water's density, with the modelled vial mass peaks near 4 °C, corresponding to the maximum density of water. The measured vial mass follows a similar pattern, decreasing as temperature increases and density decreases. There are also error bars to show the ±2°C error in the meat thermometer.

Testing the Thermometer

When we were trying to calibrate the vials, we used a glass beaker on a hot plate. The beaker broke so to actually test our thermometer, we used a pot in the kitchen. It worked at ice water up to 70℃. I noticed that because vials were floating as the water in the pot heated up, there was an added surface tension keeping the vials floating. To fix this and reduce the chances of surface temperature affecting the buoyancy, I would poke at it every few seconds. However, once the thermometer hit about 70℃, bubbles started to form on the bottom of the vials. This caused the already sinken vials to float a bit and caused the floating vials to not sink at all.

Conclusion

Fig. 5: Left shows ice water configuration, where all but the ice water vial float. Right shows 20-40℃ configuration where the 40℃ vial floats and the 20 ℃ vial sinks at 28.9℃.

Analysis

Measured results show qualitative agreement with the model prediction: the neutral buoyancy mass of the vials decreases with increasing temperature. This confirms the governing physical mechanism of temperature dependent fluid density.

Quantitatively, the model underpredicts the required vial masses by approximately 0.6–1.0 g across the full temperature range. This mismatch motivated an experimental iteration, in which vial volume was increased and neutral buoyancy was determined empirically, improving qualitative agreement. Then, based on the thermometer testing, we realized the assumption that surface tension effects are invalid, as small surface forces significantly influenced whether vials stayed floating or sank. Additionally, uncertainty in the reference thermometer and temperature gradients within the tube contributed to discrepancies.

Reflection

One surprising aspect of this project was the extreme sensitivity of buoyancy to small mass changes. Differences of less than 0.01 g were sufficient to determine whether a vial floated or sank, emphasizing the precision required in density-based measurements.

If this project were repeated, improvements would include using a narrower tube to reduce fluid volume and speed up thermal equilibration, allowing vials to stack vertically for easier readability, and designing vials with pointed ends to reduce surface tension effects. These changes would improve both accuracy and usability of the thermometer.