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The Measurement of Temperature Change in an Adiabatic Expansion

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Abstract. An experimental method for measuring the temperature change undergone by a gas during an adiabatic expansion is discussed. The experiment makes use of a thermistor as the temperature-measuring device. The procedure gives agreement within one to two percent of the theoretical values.

An adiabatic process is defined as one in which there is no heat flow, or, in thermodynamic terms, $d'q = 0$. The theory for the adiabatic expansion of an ideal gas is quite simple, and freshman physics students have been working problems involving this process for generations. One result which is immediately evident when the equation for adiabatic change is combined with the equation of state is that the gas should experience a temperature change as it undergoes an adiabatic process. As far as is known to the authors, however, no good experimental measurements of these temperature changes have been reported in physics literature. The reason for this is quite simple. Although, theoretically, an adiabatic change can be easily observed in any system possessing perfect thermal insulation, no such system can be found in practice. The only alternative is to make the required measurements quickly, before the rather small temperature changes which take place can be destroyed by the heat conduction of the system's walls. An ordinary thermometer is obviously useless. A thermocouple might be used, but the heat capacity of the junction head is likely to cause too great a time delay to give useful data.

An experimental procedure has now been devised which eliminates many of the problems involved, and which has produced remarkably good results. The experiment is simple enough to be profitably included in the laboratory part of a college thermodynamics course.

The temperature-measuring device used in the experiment is a thermistor, a piece of semiconductor having a very high negative thermal coefficient of electrical resistance. By placing the thermistor across the x-arm of a Wheatstone bridge and recording the unbalance of the bridge with a potentiometer, a picture of the temperature change is obtained. A thermistor with the smallest possible heat capacity and shortest response time is desired. A Veco type 32A50, having a one-half second

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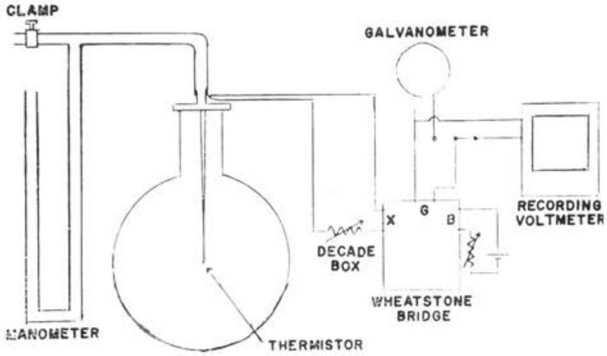

Figure 1. Block diagram of apparatus.

time constant, was used with satisfactory results. The response of the recording system must also be fairly fast.

The apparatus is fairly simple (Figures 1 and 2). A large bottle (5 liters) having an easily removable top with nipple is required. A tube runs from the top to a manometer and beyond to a clamp. The thermistor passes through the top into the bottle, and is positioned close to the center of the bottle. A decade resistance box is placed in series with the thermistor, and the wires are attached to the x-arm of a Wheatstone bridge. A galvanometer and a recording millivoltmeter, the latter to record bridge unbalance, are placed across the galvanometer terminals. The rheostat placed in series with the battery allows a convenient voltmeter deflection to be chosen.

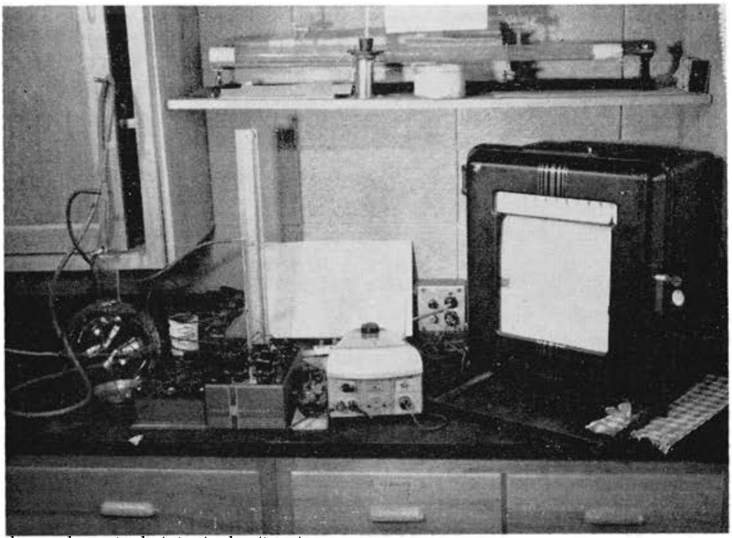

Figure 2. Apparatus arrangement.

Air is pumped into the bottle to create an excess partial pressure (between 1½ and 2 cm Hg was found to be convenient), and the air is given time to come to thermal equilibrium with the surroundings. With the decade box set at zero, the resistance of the thermistor is measured. The recording millivoltmeter is then placed in the circuit and the bottle is opened, allowing the compressed air to expand adiabatically. The resultant resistance change undergone by the thermistor is pictured on the moving tape by the voltmeter. After allowing sufficient time for the system to return to room temperature, resistance is added in convenient steps with the decade box. This provides a simple calibration for each trial.

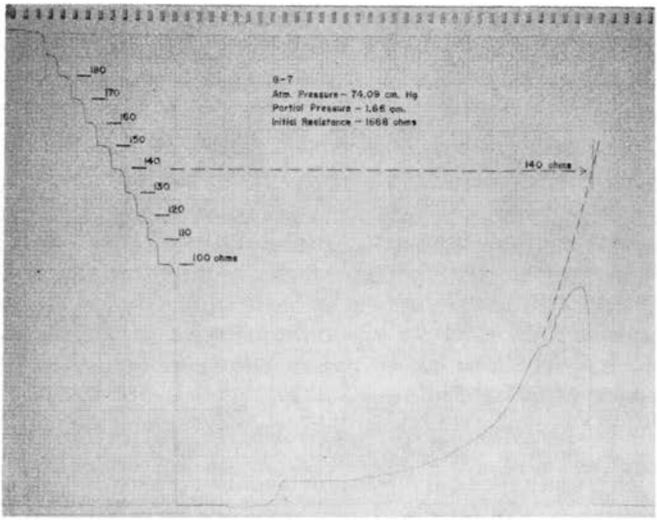

Figure 3. Comparison of theoretical value (horizontal line) and extrapolated prediction. There is a time break between the warming curve and the calibration lines. The time scale is 6 inches per minute (10 spaces per inch) running from right to left.

The warming curve is then extrapolated back to t=0, that is, the point at which the bottle was first opened (on the graph shown, time moves from right to left). It was found that only the smooth part of the curve, the true warming curve, should be used for this purpose, with the part taken before the curve settles down being ignored. This gives an experimental estimation of the amount the resistance of the thermistor would have changed had all responses been instantaneous.

At this point, we wish to see what the theoretical change should have been. For this, three equations are required: the ideal gas equations $P_1V_1/T_1 = P_2V_2/T_2$ and $P_1/P_2 = \gamma \log V_2/V_1$ and the thermistor equation $R_X = R_A \exp B(1/T_X - 1/T_A)$ where absolute temperature T_A, and its corresponding resistance R_A, are arbitrary reference values chosen when the thermistor is calibrated. Air is, of course, not an ideal gas, but its deviation is negligible compared to the other uncertainties in the experiment. Gamma, the ratio of the specific heats, is taken as 1.40. Since the initial resistance of the thermistor, R_x, is known, the initial temperature can be calculated. As all pressures and the volume of the bottle are known also, the gas equations yield the temperature after adiabatic expansion. Putting this value back into the thermistor equation, the new resistance, and therefore the resistance change, can be found. When this is compared with the change which was predicted experimentally, the correlation is found to be within one percent.

An exponential French curve was used to make the extrapolation shown here. If a more analytical approach is desired, the curves may be considered as Newton's cooling curves, that is, exponential decay curves, and their equations can easily be found. Solving the equations at $t=0$ yields substantially the same results as the graphical extrapolation.

Since temperature-sensitive devices are now available and the associated circuitry is relatively unsophisticated, it is suggested that the measurement of the adiabatic temperature change is much more fundamental than the traditional approach. The method may be used for the determination of gamma simply by working backwards, but, while this is the principal aim of the older experiments, it is but part of a more inclusive and interesting perspective which the new experiment demonstrates. The procedure is easily applicable to the study of other gases, and, with equipment modification, should be capable of producing results of the same order of accuracy as is given by more limited methods.