Approach To Absolute Zero

1. Liquefaction Of Gases

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Absolute zero of temperature is unattainable. One may approach as close to absolute zero as technically possible. In this four part series an attempt will be made to trace developments in the approach to absolute zero. In Part I, I will explain the principles governing liquefaction of gases.

Introduction

Temperature is a measure of the hotness or coldness of an object. It can be measured with a thermometer. The thermometer contains a working substance such as a liquid in a liquid-in-glass thermometer or a wire of some metal in a resistance thermometer. Some property of the substance varies with temperature such as the volume of a given mass of liquid or the resistance of a given piece of wire. To calibrate the thermometer one chooses two standard baths, say a bath of melting ice and a bath of water boiling at one atmosphere pressure. The thermometer is brought into good thermal contact with each bath and the value of the property measured. Arbitrary values are given to the temperatures of the two baths to define a scale of temperature. In the centigrade scale these values are zero for the ice bath and 100 for the boiling water bath. Assuming the value of the property to vary linearly with temperature, one can find the temperature of any other object by bringing the thermometer in contact with the object and measuring the value of the property. It is obvious that the temperature of an object measured using two different thermometers containing different working substances may not agree with each other. Also there is no a priori limit for the lowest temperature of an object. The temperature of an object can be negative without any limit. Thus the scale of temperature chosen is not an absolute one.
All gases under low pressure and high enough temperature obey Boyle’s law

\[ PV = f(t), \]

where \( P \) is the pressure of the gas, \( V \) the volume of \( n \) moles of the gas and \( f(t) \) is a function of temperature. A gas which obeys the above relation at all temperatures and pressures is called an ideal gas. No gas is ideal. Every gas approaches the ideal gas behavior at low pressures and high temperatures. We may define a scale of temperature, called the ideal gas scale, in which we may assume \( PV \) to vary linearly with temperature. Experiments indicate that the function \( f(t) \) in the ideal gas scale is

\[ f(t) = nR(t_c + 273.16), \]

where \( t_c \) is the temperature on the centigrade scale and \( R \) is the gas constant. If one measures the pressure of a constant volume of gas the temperature values obtained with different gases as working substances will differ very little, especially if the pressure of the gas is low and the temperature is high. To this extent the gas thermometer is superior to the liquid-in-glass or resistance thermometers. However even this thermometer is not absolute as one can choose the zero of temperature at will.

**Absolute Temperature Scale**

Two remarkable discoveries were made in the study of the efficiency of heat engines initiated by Sadi Carnot, a French engineer. A heat engine absorbs a quantity of heat \( Q_1 \) from a high temperature heat reservoir, rejects a quantity of heat \( Q_2 \) to a heat reservoir at a low temperature and performs external work \( W \). It is found that heat absorbed at the higher temperature cannot be completely converted into work. Considering an ideal engine in which the processes take place infinitesimally slowly, so that the working substance is in thermodynamic equilibrium throughout the cycle and the cycle is reversible, it can be shown