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Calibration of
Temperature Measuring Devices

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Calibration of Temperature Measuring Devices: 77K to 300K

Purpose

The purpose of this experiment is to explore new ways to measure temperature. In the process, one should become familiar with crucial revolutionary experimental processes. This involves setting up an experiment in such a way that a computer can make rapid and precise measurements. It is also necessary to create a computer program to manipulate the data, or become familiar with software that can do this. This is called an introduction to the HP-IB bus method of interfacing to experimental equipment.

Introduction

The most commonly used thermometers is said to be the mercury and ideal gas thermometers. In each case, the volume of the substance is dependent on its temperature. Consider a sealed tube containing mercury. As the temperature rises, the volume of mercury increases, and it is seen to rise up the tube. It turns out this is a linear relationship, meaning that if one were to make evenly spaced etches on the tube, then as the mercury column passed from etch to etch, the temperature difference between etches would be identical. It is in this way that the early temperature scales such as the Celsius and Fahrenheit scales were developed. There are other ways to measure temperature. The speed of sound in a given medium is also dependent on temperature.

An additional method of measuring temperature would be the '**thermocouple**'. This device can make temperature measurements with a high degree of precision. The theory behind the thermocouple is as follows: the atoms of a metal have what is called a Fermi energy. This energy is related to the outermost valence electrons that are capable of conduction. This Fermi energy is at a certain Fermi level unique to that metal. When another metal is brought into contact with the first, their Fermi energies must be the same. However each Fermi level is at a different electrical potential, and when the surfaces are brought into contact, there will be a potential difference called the contact potential. Because Fermi levels are dependent on temperature, it follows that the contact potential changes as the temperature does. This is called the thermoelectric effect, otherwise known as the Peltier effect.

Another would be a '**semiconductor**'. The valence bands of Carbon and Silicon are full. The gaps between these bands and the lowest energy state of the next band up is typically not very large. The 'next band up' is referred to as the conduction band. As the temperature of the solid is raised, electrons from the top of the valence band may gain sufficient energy to reach the conduction band. Charge can then be transported. Conductivity in semiconductors is generally much less than that of metals. However, the conductivity of these semiconductors increases rapidly with an increase in temperature. The resistance of the substance decreases significantly. Conversely, at low temperatures, the resistance becomes very high. Measurement of the resistance in certain temperature ranges results in high precision temperature measurements.

A **diode** consists of a semiconductor with a junction. A diode is primarily made up of silicon or germanium. These elements are found under column IV of the Periodic

Table of Elements. This column contains elements with four valence electrons, and tend to be very stable. On one side some of the atoms are replaced with pentavalent atoms, elements of column V of the Periodic Table. One of the five electrons of this atom is very easily promoted to the conduction band, and the 'impure' atom is considered to be a *donor*. On the other side, some atoms are replaced with trivalent atoms, column III. The valence band is lacking an electron to complete bonding with surrounding atoms, and so the 'impure' atom is considered an *acceptor*. At the junction, some donors will supply some of the acceptors with electrons, until an electric field is created that prevents further transfer.

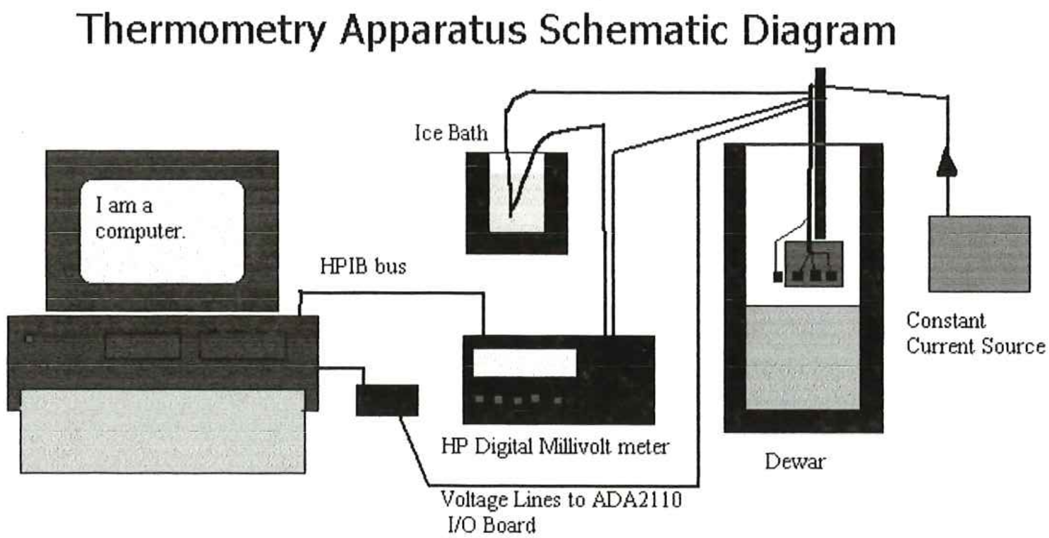
Current flow across this diode junction is temperature dependent. An equation for this is $I = I_0(e^{(eV/kT)}-1)$. Maintaining a constant current results in the voltage across the junction being linear with temperature: $V = kT/e\ln(I/I_o-1)$.

Finally, temperature dependence is found on the electrical resistance of **metals.** As the temperature increases, there are more ion vibrations which cause more and more scattering of electrons. This scattering hinders the movement of electrons in any particular direction, causing the resistance to increase, proportional to the temperature increase.

Experiment

Four types of thermometers are used in this experiment. A 'probe' has attached to it all four types on an aluminum block. The temperature of the block should be changed slowly to ensure all thermometers are at the same temperature. The four thermometers are as follows:

a) A chromel-alumel thermocouple junction (K-type)
   Chromel = 90% Ni, 10% Cr
   Alumel = 96% Ni, 2% Mn, 2% Al
b) A platinum resistor of 100 ohms at room temperature
c) A carbon composite resistor of 220 ohms
d) A silicon junction diode



The resistors and junction diode are supplied with a constant current of 10 milliAmps. It may be unclear from the diagram, but separate sets of wires deliver the currents, and separate sets are connected to their terminals to measure the individual voltages. So long as no resistance exceeds 1200 ohms, the current source should remain constant. Note, there are to be separate common grounds for the currents and voltages.

The thermocouple requires a reference junction at a known temperature. An ice bath will maintain this constant temperature reference at 0°C.

Making Measurements

At this point a computer really comes in handy. Four voltage measurements must be made simultaneously. This should also be done quickly to be sure that measurements are made over the smallest possible temperature range. The voltages from the resistors and diode may be measured directly with an A/D conversion board in the computer. The thermocouple voltage, however, is in the millivolt range, and cannot be measured with ordinary operational amplifiers. This is because the op-amps typically have offset input voltages of millivolts, and this would lead to enormous errors. Fortunately there is such a thing as a Hewlett-Packard precision digital millivolt meter that can be connected to a HP-IB board to measure the thermocouple voltages.

Procedures

A computer program may be devised with software such as Labview that will measure three thermometer voltages using the A/D board, and also to command the millivolt meter to make measurements of the thermocouple voltage, sending the reading back to the computer. The program should make frequent measurements so that the entire range of temperatures the probe encounters may be examined. The resulting data should be written to a file to be analyzed at a later time.

- Fill the dewar half way with liquid nitrogen.
- Attach a thermometer probe to the computer and be sure the program works.
- Dunk the probe into the liquid nitrogen. Once the probe has reached the temperature of the liquid nitrogen (77K), begin measurements. Raise the probe to a level slightly above the liquid. Carefully allowing the probe to warm up slowly, gradually raise the probe. Cease measurements when the probe appears to have reached room temperature (300K). Coincidentally, this process may also be done in reverse.

The thermocouple provides a secondary temperature scale. Tables in a CRC Handbook can be used to convert the thermocouple voltages to temperature. Other sources for conversion may be found also. Using these temperatures, plot graphs of resistance versus temperature for the resistors used, and voltage versus temperature for the diode.

Determine the accuracy of the thermometers. Use the voltage step of one digit on the A/D conversion and convert to temperature range for each thermometer. Plot graphs of accuracy versus temperature for the three thermometers. Also include a graph for the thermocouple using the precision possible with the millivolt meter.

Results

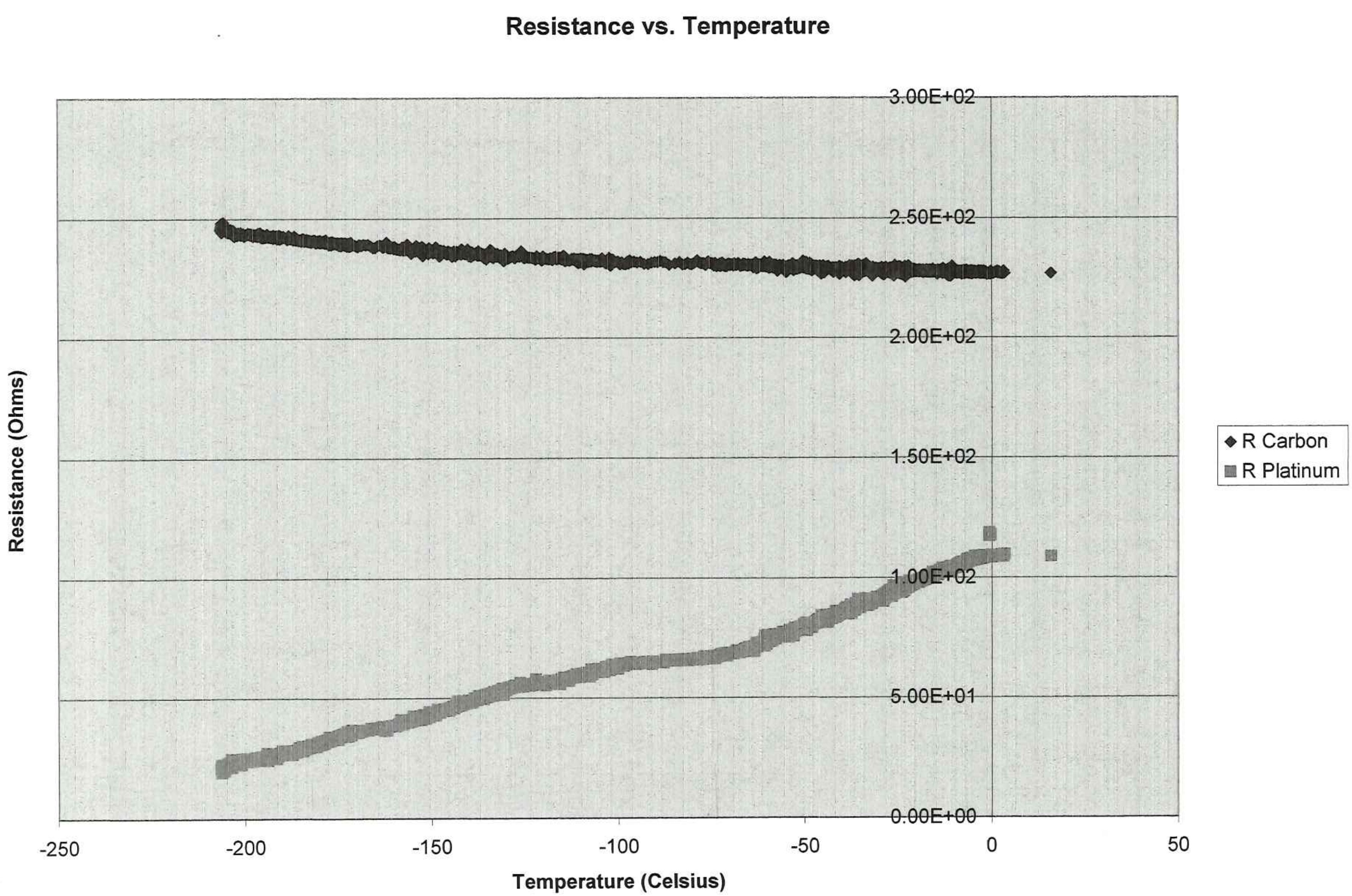
With the use of the computer software 'Labview', version 5.0, a great deal of data was collected and stored on disk. The computer continuously read the voltages of each lead, and saved the values. The equation for converting the thermocouple voltages to a temperature in Celsius is: First, $k = V\cdot 10^{6}$, then

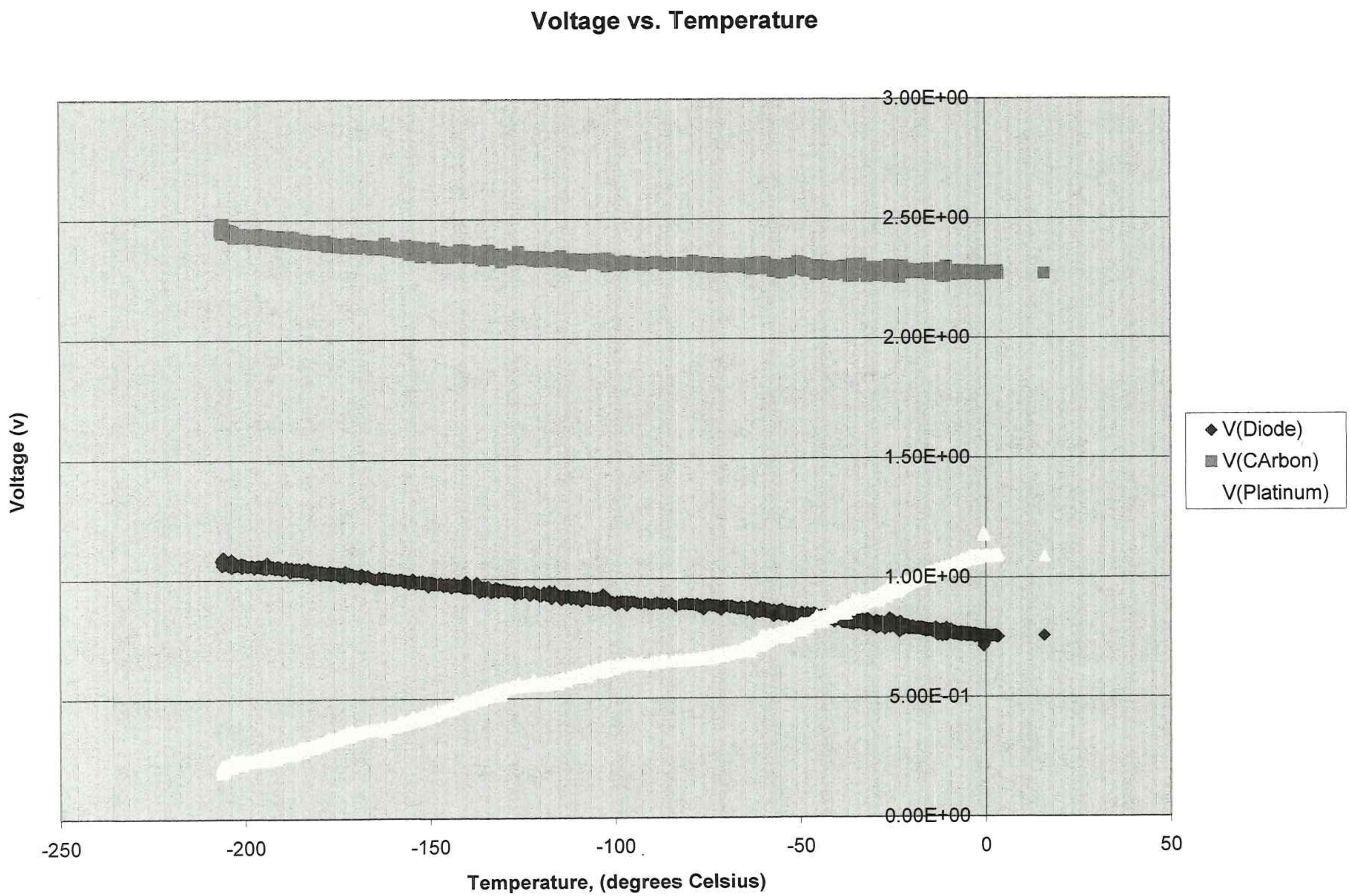
$$T = k(2.52\cdot10^{-2} + k(-1.17\cdot10^{-6} + k(-1.08\cdot10^{-13} + k(-3.73\cdot10^{-16} + k(-8.66\cdot10^{-20} + k(-1.05\cdot10^{-23}+k(-5.19\cdot10^{-28})))))))$$

Note that this equation is specific to the thermocouple used, and a repeat of this lab should involve double-checking the appropriate conversion formula in a CRC handbook. ✓

The results are plotted on the following graphs. Remember, to summarize what is expected as the temperature increases, I present the following reference table:

Substance:	**Reaction to Temperature Increase**
Platinum Metal	Resistance increases due to scattered electron movement
Carbon Semiconductor	Resistance decreases as electrons pushed into valence band
Silicon Diode	Voltage potential barrier decreases


Resistance vs. Temperature
3.00E+02
2.50E+02
2.00E+02
1.50E+02
1.00E+02
5.00E+01
0.00E+00
Resistance (Ohms)
-250
-200
-150
-100
-50
0
50
Temperature (Celsius)
R Carbon
R Platinum



Voltage vs. Temperature
Voltage (v)
3.00E+00
2.50E+00
2.00E+00
1.50E+00
1.00E+00
5.00E-01
0.00E+00
-250
-200
-150
-100
-50
0
50
Temperature, (degrees Celsius)
V(Diode)
V(CArbon)
V(Platinum)

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Discussion

One might not think that the items used would make suitable thermometers. The results clearly show temperature dependence of certain properties, which is what is more important to note. Since the temperature range is so large, it is interesting to note that the resistance of the carbon semiconductor changes so little, while the resistance of the platinum metal changes by almost two orders of magnitude. One might think that the large variance of resistance of the platinum would make it suitable as a thermometer. However, the resistance is not quite linear, as it levels of a bit in the –100 to –75 degree Celsius range.

Despite the non-linear resistance dependence on temperature of the platinum over the entire temperature range, it is quite linear in the –80 to –10 degree Celsius range, and could be calibrates for thermometer use in this range. The voltage dependence of the diode on temperature may also allow it to be calibrated and used as a thermometer device, which is not uncommon.

Questions

Q: Why can the wires measuring the voltages not be used to carry the current to the thermometers?
A: The current being supplied to the thermometers must remain constant, and the voltage measurements must remain independent of this current supply to avoid current variance.

Q: There are Joule heating losses in the thermometers which can raise the temperature of the thermometer above that of the surroundings. Is that a problem in this experiment?
A: This is not a problem for two reasons. One is that the losses are so minimal compared to the variance in the measurements at each temperature. The other is that the main goal of this experiment is simply to illustrate the temperature dependence of different items.

Q: Why is it necessary to have a reference junction as well as the temperature measuring junction when using the thermocouple?
A: The thermocouple works by comparing the potential difference of the temperature measuring junction to the reference junction, which must remain constant or the comparison becomes meaningless. It might be possible to allow the temperature of the reference junction to vary, but then new steps must be taken to measure the reference temperature constantly, and match it to each measurement, which simply introduces major complications and sources of error.

Conclusions

New methods of temperature measurement have been explored. The real temperature dependent properties was clearly evident. Familiarization was gained with computer data monitoring, and a new lab environment.

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& error estimate
on file

References

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Aggregates of Atoms; Molecules and Solids
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