

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Thermodynamics of Materials

3.00 Fall 2000

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Exam 1: Friday October 6, 2000 (11:05-11:55AM)

Exam Question 1.1

Consider three isolated systems that are initially composed of an iron spring and a vat of hydrochloric acid. The three systems are identical except for the initial state of the iron spring.

The spring has a mass of 10 grams and has a length of x_0 if no force is applied to it. The relationship between the applied force, F , and the length, x , of the spring is: $F = -k(x - x_0)$ where k is a spring constant that is independent of x and temperature.

The vat of hydrochloric acid is initially at -100°C and can dissolve 1 kilogram of un-stretched iron (also initially at -100°C) and the complete dissolution will cause a temperature rise of 10° .

Demonstrate how or find an expression that you would estimate the final temperature of the system for three different cases:

System A (no force)

The iron spring (mass of 10 grams, initial temperature -100°C) of length x_0 is dissolved in the vat at constant length.

Internal energy is stored as a chemical reaction—the dissolution of iron in HCl. In a closed system, the internal energy must be conserved and as indicated by the data shows up as a temperature change in the system. Because internal energy is an extensive quantity, if 1×10^3 grams produces a temperature change of $\Delta T = 1 \times 10^1^\circ\text{C}$, then 1×10^1 grams would produce a change of $\Delta T = 1 \times 10^{-1}^\circ\text{C}$.

System B (compression)

The iron spring (mass of 10 grams, initial temperature -100°C) is initially compressed to a length $x_0/2$ and then dissolved in the vat at constant length.

There is an internal energy in the spring. All the energy will show up as heat. We may divide the heat into two parts, that which is stored as internal energy of the spring and that which is stored in

the chemical reaction of dissolution. The internal energy of the spring is:

$$\Delta U = \int_{x_o}^{x_o/2} k(z - x_o) dz = \frac{kx_o^2}{8}$$

Therefore the temperature change will be that due to the reaction plus the conversion of the energy of the spring.

$$\Delta T = \Delta T_{rx} + \frac{kx_o^2/8}{C}$$

where C is the effective heat capacity of the HCl solution.

System C (tension)

The iron spring (mass of 10 grams, initial temperature -100°C) is initially stretched to a length $3x_o/2$ and then dissolved in the vat at constant length.

The extra internal energy of the spring in tension is:

$$\Delta U = \int_{x_o}^{3x_o/2} k(z - x_o) dz = \frac{kx_o^2}{8}$$

the same as that of a spring in the equal amount of compression (System B). Again,

$$\Delta T = \Delta T_{rx} + \frac{kx_o^2/8}{C}$$

where C is the effective heat capacity of the HCl solution.

If possible, rank the three systems, from highest final temperature to lowest final temperature.

The systems B and C have identical amounts of stored internal energy. Therefore,

$$T_B = T_C > T_A$$

Exam Question 1.2

The CRC, Handbook of Chemistry and Physics, 58th edition, defines the *Latent Heat of Vaporization* as follows:

The quantity of heat necessary to change one gram of liquid to vapor without change in temperature, measured in calories per gram.

As defined, what kind of thermodynamic quantity is the latent heat of vaporization?

As defined it is a “derived intensive quantity” since it is the quotient of two extensive quantity. It is not necessarily a state function, since the amount of work that accompanies the change is not specified.

Suppose you were to measure the latent heat of vaporization of an unknown material. When you report your results to the rest of the world, would you need to augment the CRC definition in any way? If so, be specific.

At a very minimum, one must report the temperature and/or pressure that the experiment was done. If the system is held at constant volume during the phase change, this would effect the numerical answer. Any experimental conditions that may reasonably Effect the result would need to be reported.

Exam Question 1.3

Consider a closed system comprised of 3.00 moles of an ideal monatomic gas with an initial state P_0 and V_0 .

After some unspecified process, the final state is $P_0/3$ and $3V_0$.

If possible, compute a result, develop an expression, or clearly describe how you would answer the following two questions:

What is the change in the molar internal energy of the ideal gas system?

From the ideal gas law $PV = nRT$, the temperature of the final state is equal the temperature of the initial state. Because the internal energy U is a function only of T for an ideal gas and because it is a state function, $\Delta U = 0$.

How much work was performed *by* the system upon the universe?

Without a specified reversible path, it is impossible to determine this quantity from the endpoints. The work performed cannot be determined.