Chapter 8

1

Thermodynamics

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Thermodynamics

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Thermodynamics involves situations in which the temperature of a system changes due to energy transfers.

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Internal Energy

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- **Internal energy** is all the energy of a system that is associated with its microscopic components. These components are its atoms and molecules.
- Internal energy includes kinetic energies due to:
  - Translational motion
  - Rotational motion
  - Vibrational motion
- Internal energy also includes potential energy between molecules.
- SI unit: Joules.

Heat

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- **Heat** is defined as the amount of energy transferred across the boundary of a system due to a temperature difference between the system and its surroundings.
- SI unit: Joules.

Thermal Contact and Thermal Equilibrium

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- Two objects are in thermal contact with each other if energy can be exchanged between them.
  - The exchanges we will focus on will be in the form of heat.
- The energy is exchanged due to a temperature difference.
- Thermal equilibrium is a situation in which two objects would not exchange energy by heat if they were placed in thermal contact.

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Temperature – Definition

6

Temperature is the property that determines whether an object is in thermal equilibrium with other objects.

Two objects in thermal equilibrium with each other are at the same temperature.

Temperature is something that determines whether or not energy will transfer between two objects in thermal contact.

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Celsius Scale

7

A thermometer is a device that is used to measure the temperature of a system.

The steam point of water is defined to be 100^{o} C.

The ice point of water is defined to be 0^{o} C.

The length of the column between these two points is divided into 100 increments, called degrees.

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Fahrenheit Scale

8

A common scale in everyday use in the US

Temperature of the ice point is 32^{o}F.

Temperature of the steam point is 212^{o}F.

There are 180 divisions (degrees) between the two reference points.

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Absolute Scale

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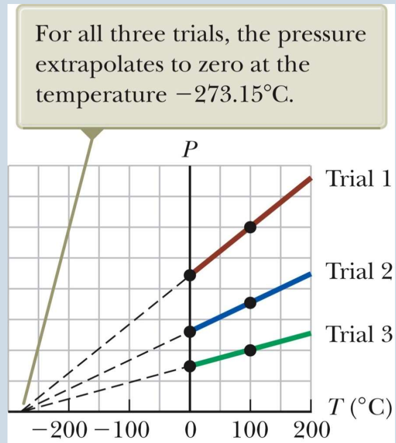
- If the lines for various gases are extended, the pressure is always zero when the temperature is –273.15° C.
- This temperature is called absolute zero.
- Absolute zero is used as the basis of the absolute temperature scale.
- The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale (100 degrees).



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Comparison of Scales

10

Celsius and Kelvin have the same size degrees, but different starting points.	$T_C = T_K - 273.15$
Celsius and Fahrenheit have different sized degrees and different starting points.	$T_F = \frac{9}{5} T_C + 32$
To compare changes in temperature.	$\Delta T_C = \Delta T_K = \frac{5}{9} \Delta T_F$
Ice point temperatures.	$0\ ^{\circ}C = 273.15\ K = 32\ ^{\circ}F$
Steam point temperatures.	$100\ ^{\circ}C = 373.15\ K = 212\ ^{\circ}F$

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Comparison of Scales

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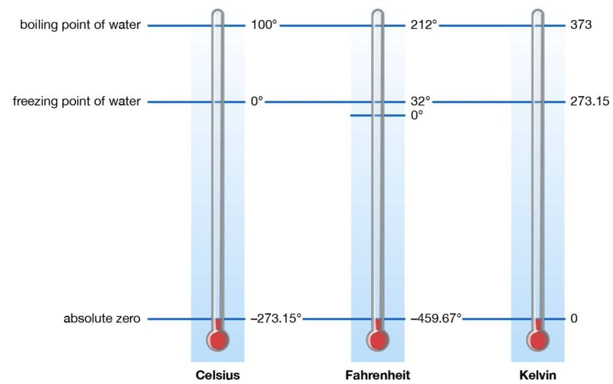

General formula:

- $\frac{T_C - 0}{100} = \frac{T_F - 3}{180} = \frac{T_K - 273.15}{100}$

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Pressure

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Pressure is the ratio of the magnitude of the normal force applied divided by the surface area:

$$P = \frac{F}{A}$$

Pressure is a scalar quantity, and the SI unit is the Pascal (Pa):

$$1Pa = 1\, N/m^2$$

The **atmospheric pressure** (atm) is:

$$1\ atm. = 1.013 \times 10^5\ N/m^2 = 760\ mmHg$$

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Zeroth Law of Thermodynamics

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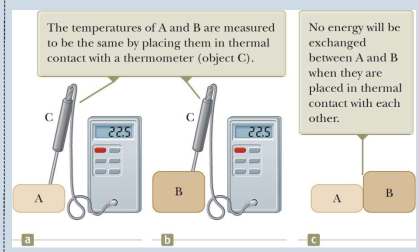
"If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other."

- Let object C be the thermometer
- Since they are in thermal equilibrium with each other, there is no energy exchanged among them.



Work in Thermodynamics

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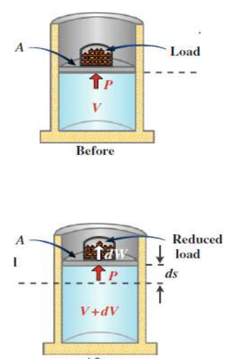
A gas confined to a cylinder with a movable frictionless piston of area A.

At equilibrium, the upward force on the piston due to the pressure of the confined gas is equal to the weight of the load on the top of the piston.

Now, assume we reduce the load from the piston in such a way that the piston will move upward through a displacement (Δy) with constant force (f).

The process slow enough to keep the system in thermal equilibrium.



Work in Thermodynamics

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- The work done by the gas is:

$$W = F\Delta r cos\theta = PA\Delta y$$

- P: pressure in N/m^2

$$P = \frac{F}{A}$$

- $(A\Delta y)$ is the change in volume of the gas, (ΔV).
- Therefore, the work done by the gas is

$$W = P\Delta V = P\left(V_f - V_i\right)$$

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Work in Thermodynamics

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If the gas expands, then ΔV is positive and the work done by the gas is positive,

If the gas is compressed, ΔV is negative, indicating that the work done by the gas is negative (which can be interpreted as work done on the gas).

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The First Law of Thermodynamics

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The First Law of Thermodynamics states that:

"the change in internal energy of a system will be equal to the energy added to the system by heating minus the work done by the system".

$$\Delta U = Q - W$$

- All quantities are in (Joule).
- U: is the internal energy.
- The first law of thermodynamics is a special case of the law of conservation of energy.

The First Law of Thermodynamics

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work is positive when it is done by the system and negative when it is done on the system,

heat is positive when it is added to the system and negative when it is withdrawn from the system.

Internal energy is positive when temperature is increased and negative when temperature is decreased.

The Second Law of Thermodynamics

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Clausius statement:

Heat can never pass from a colder to a warmer body without some other change, occurring at the same time.

Heat cannot spontaneously flow from cold regions to hot regions without external work being performed on the system.

For example, in a refrigerator, heat is transferred from cold to hot, but only when forced by an external agent, the refrigeration system.

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Temperature scales-2

Sunday, 17 October, 2021 21:10

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.
- Kane

The normal boiling point of nitrogen is $-195.75\ ℃$.

- What is this temperature in Kelvin and in Fahrenheit?
- If the temperature changes from $-195.75\ ℃$ to $-100\ ℃$, find the change in the temperature on the Fahrenheit scale.

Solution

The temperature in Kelvins is:

$$T_K = T_C + 273.15 = -195.75 + 273.15 = 77.4K$$

The temperature in degrees Fahrenheit is:

$$T_F = \frac{9}{5}T_C + 32 = \frac{9}{5} \times^- 195.75 + 32 = -320.35°F$$

Solution

$$\Delta T_F = \frac{9}{5}\Delta T_C = \frac{9}{5}(-100 - {}^-195.75) = 172.35°F$$

Pressure-1

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Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- [ ] R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- [ ] J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
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- [ ] H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.
- [x] Kane

A gas at a pressure of $10\ atm$ is in a cubical container of side $0.1\ m$. If the pressure outside is atmospheric pressure, what is the net force on one wall of the container?

Solution

The force due to gas inside is:

$$F_i = P_i A = (10atm)(1.013 \times 10^5 pa/atm)(0.1m)^2 = 1.013 \times 10^4 N$$

The force on the outside due to the atmosphere is:

$$F_a = P_a A = (1.013 \times 10^5 pa/atm)(0.1m)^2 = 0.1013 \times 10^4 N$$

The net force outward is the difference:

$$F_i - F_a = 1.013 \times 10^4\ N - 0.1013 \times 10^4\ N = 0.912 \times 10^4 N$$

In this example the force on the wall is proportional to the difference between the internal pressure P_i and the atmospheric pressure P_a. The difference $P_i - P_a$ is called the gauge pressure of the gas.

1st Law-1

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- ✓ Kane

- A gas at a pressure of $2\ atm$ is heated and allowed to expand against a frictionless piston at constant pressure. If the volume changed by $0.5\ m^3$. How much work is done by the gas?
- If $3 \times 10^5\ J$ of heat enters during the expansion, what is the change in the internal energy of the gas?

$$P = 2atm = 2 \times 1.013 \times 10^5\ N/m^2$$

$$W = P\Delta V = 2 \times 1.013 \times 10^5 \times \frac{1}{2} = 1.013 \times 10^5 J$$

From the first law, the change in the internal energy is: $U_f - U_i = Q - W$. Here heat enters the system, so Q is positive. Also work is done by the system, and W is positive as well.

Hence:

$$U_f - U_i = Q - W = (3 \times 10^5 J) - (1.01 \times 10^5 J) = 1.99 \times 10^5 J$$

Since the heat entering is greater than the work done by the expanding gas, its internal energy has increased.

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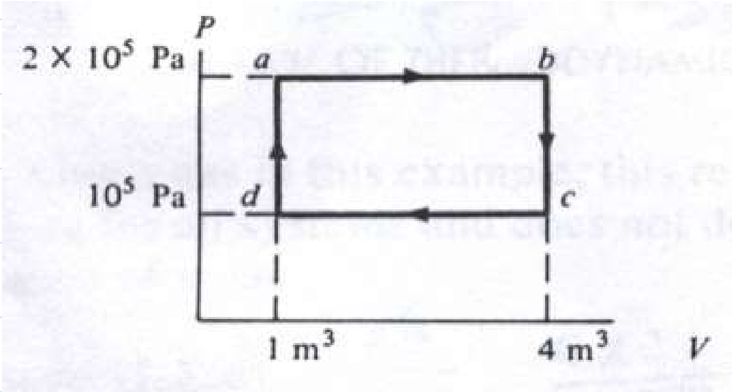
Kane

A gas undergoes a series of pressure and volume changes as shown.

- How much work is done by the gas along the path abc?
- How much work is done by the gas along the path cda?
- How much heat enters the gas during one full cycle?



Solution

From a to b, the work done by the gas as it expands at a constant pressure is:

$W_{ab} = P\Delta V = (2 \times 10^5 Pa)(4m^3 - 1m^3) = 6 \times 10^5 J$

From b to c, the volume does not change, so no work is done. Hence:

$W_{abc} = W_{ab} = 6 \times 10^5 J$

Solution

From b to c, the volume is decreasing, and $\Delta V$is negative. Thus:

$W_{cd} = P\Delta V = (1 \times 10^5 Pa)(1m^3 - 4m^3) = -3 \times 10^5 J$

The minus sign indicates work is done on the gas as it is compressed to a smaller volume. Note that this work done on the gas is less than the work it did as it expanded, since the pressure is lower. Again, no work is done in the constant volume part of the cycle from d to a, so:

$W_{cda} = W_{cd} = -3 \times 10^5 J$

Solution

Since we have gone through a full cycle, $U_f - U_i = 0$. Hence the first law, $U_f - U_i = Q - W$, becomes $Q - W = 0$. The net heat entering is:

$Q = W = W_{\text{abc}} + W_{\text{cda}} = (6 \times 10^5 J) + (-3 \times 10^5 J) = 3 \times 10^5 J$

The net heat entering the gas equal the net work it does over the cycle.