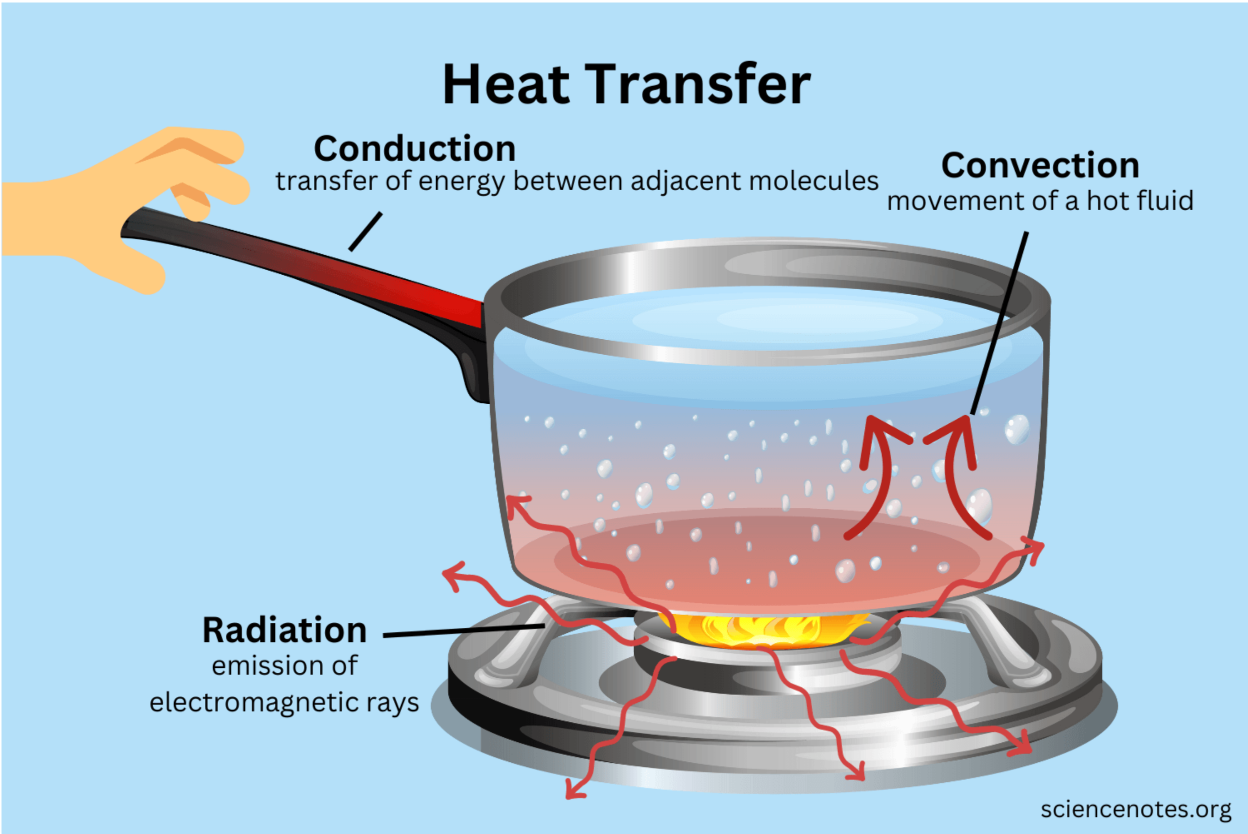
Heat & Thermodynamics

What is a simple definition of heat?

Heat is the transfer of kinetic energy from one medium or object to another, or from an energy source to a medium or object. Such energy transfer can occur in three ways: conduction, convection and radiation.



Conduction

The process by which heat or electricity is directly transmitted through the material of a substance when there is a difference of temperature or of electrical potential between adjoining regions, without movement of the material.

- the process by which sound waves travel through a medium.
- the process of heating a pan on a stove.
- the transmission of impulses along nerves.

Convection

Convection, process by which heat is transferred by movement of a heated fluid such as air or water.

- Hot air rising above a fire.
- Ice melting.
- Sea breeze or land breeze caused by a difference in pressure.

- Blood circulation in warm-blooded animals.

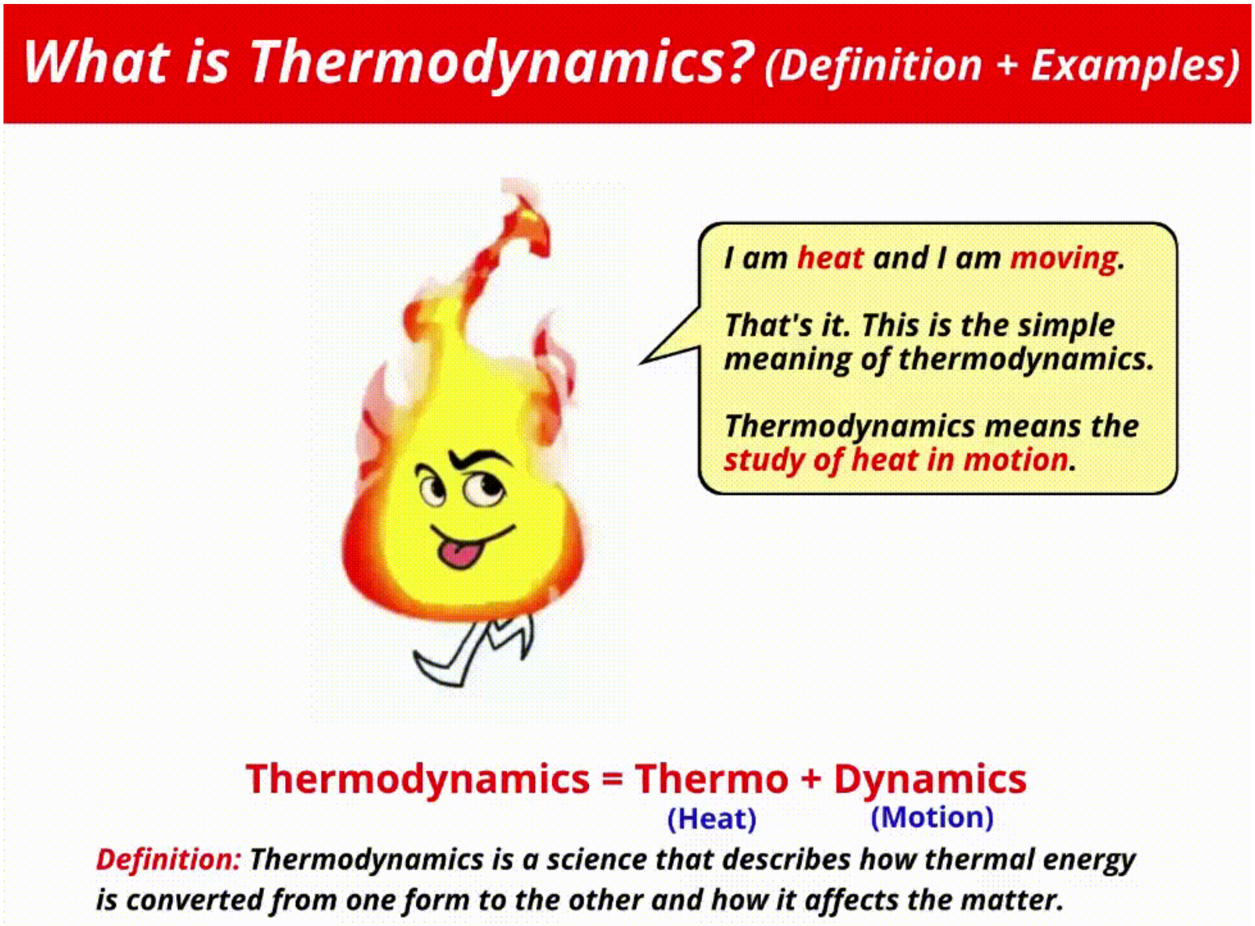
Radiation

Radiation is energy that comes from a source and travels through space at the speed of light. This energy has an electric field and a magnetic field associated with it, and has wave-like properties. You could also call radiation “electromagnetic waves”.

- Examples include heat or light from the sun,
- microwaves from an oven,
- X rays from an X-ray tube and gamma rays from radioactive elements.

Thermodynamics

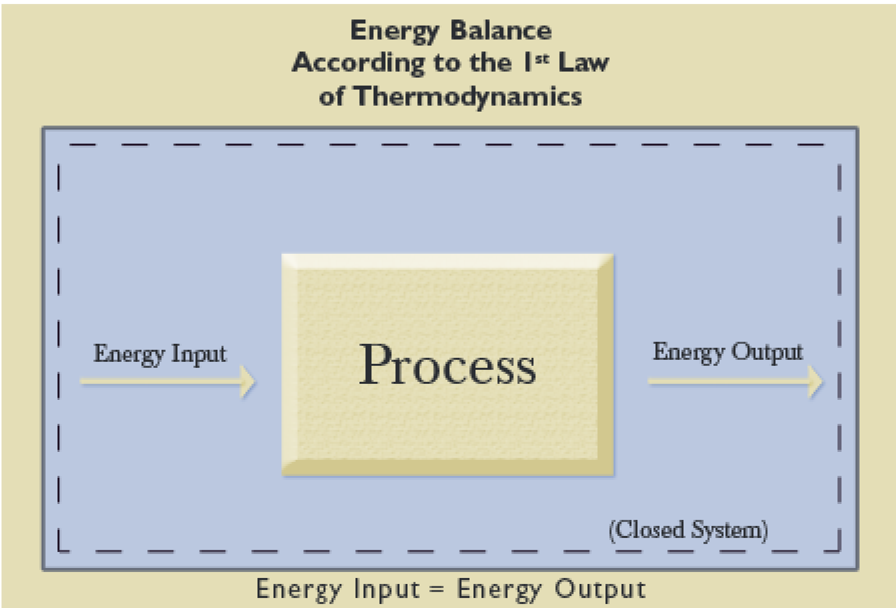
The branch of physical science that deals with the relations between heat and other forms of energy (such as mechanical, electrical, or chemical energy), and, by extension, of the relationships between all forms of energy.

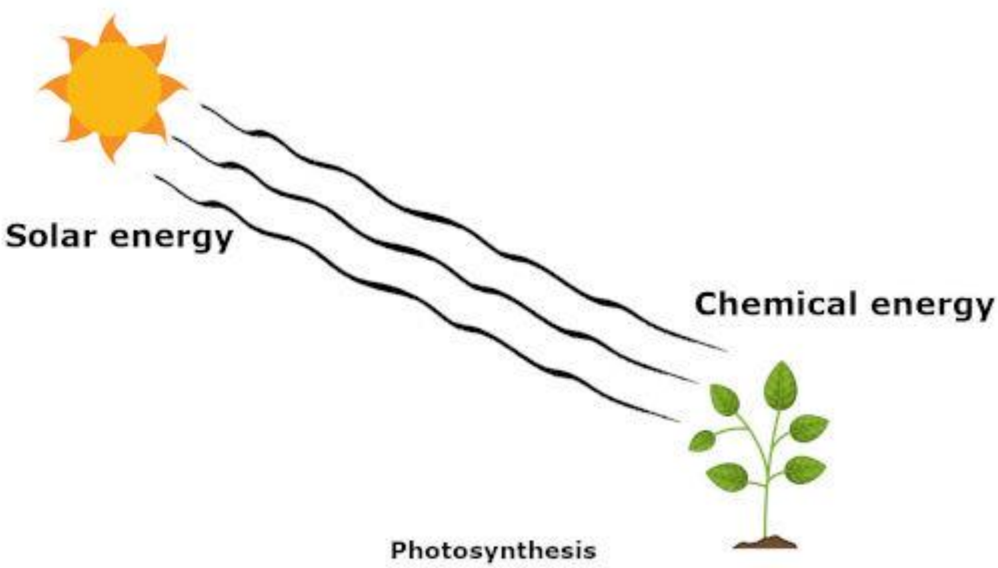


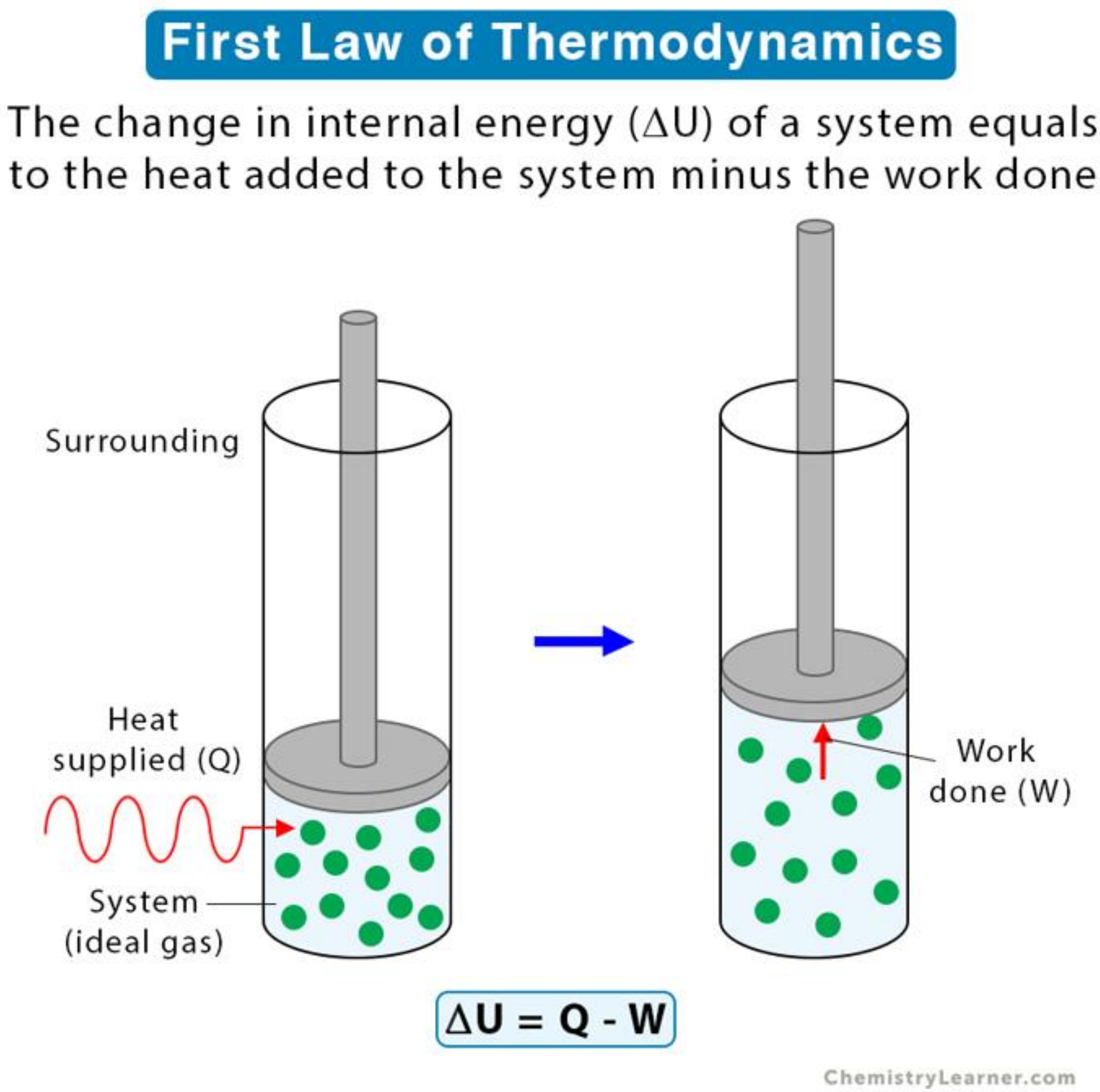
1st law of Thermodynamics

The law states that the energy entering the system in the form of heat is equal to the sum of the increase in the system's internal energy and the energy leaving the system in the form of work done by the system on its surroundings.

Phenomenon of First law



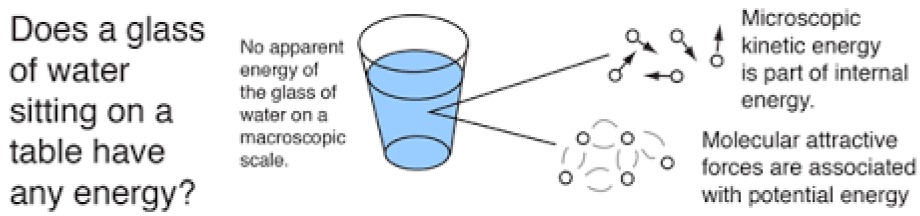


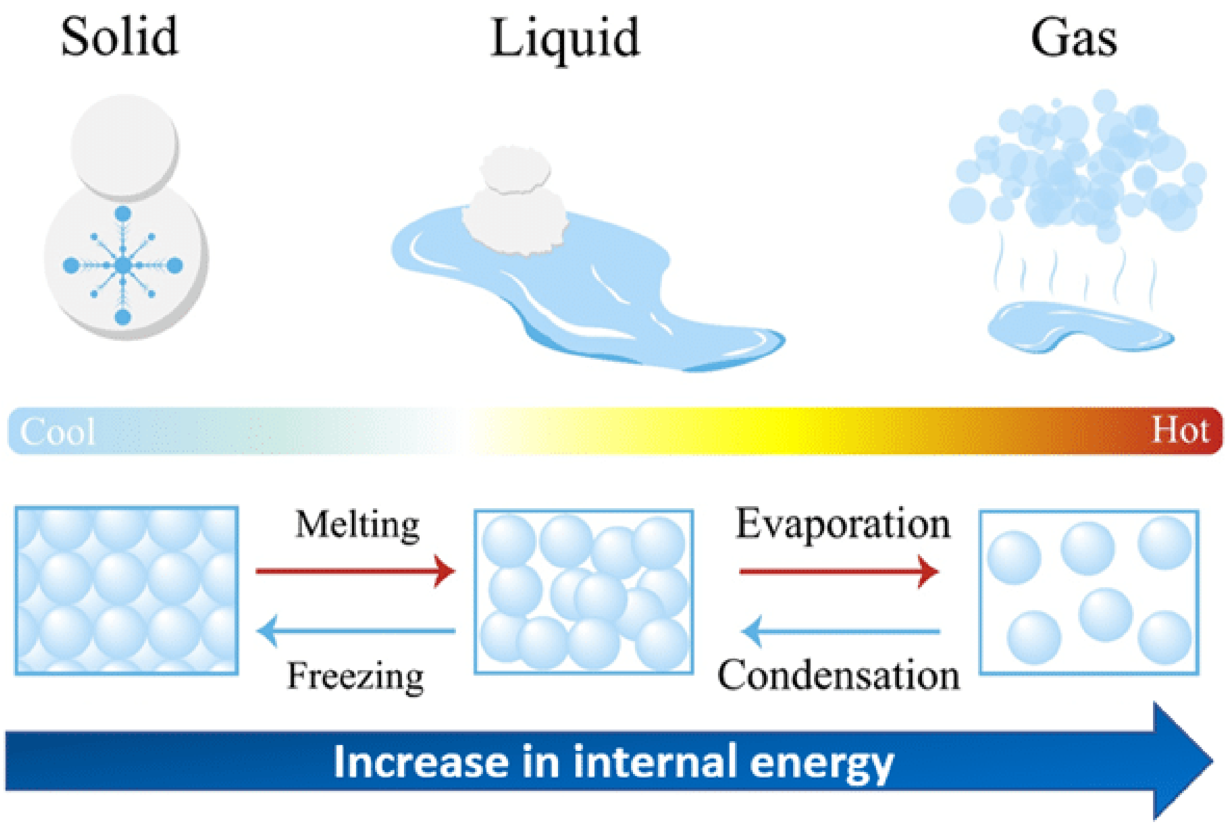


Internal energy

Internal energy U of a system or a body with well-defined boundaries is the total of the kinetic energy due to the motion of molecules and the potential energy associated with the vibrational motion and electric energy of atoms within molecules. Internal energy also includes the energy in all the chemical bonds.

The energy of a thermodynamic system that is NOT either the kinetic energy or gravitational potential energy of the system as a whole is known as Internal Energy. The internal energy is associated with the internal degrees of freedom of the system.





What are the limitations of the first law of thermodynamics?

It does not tell us about the direction of the flow of heat.
It fails to explain why heat cannot be spontaneously converted into work.

Specific heats of gases

Specific heat capacity for gas is the amount of energy required by one gram of gas to raise the temperature by unit degree Celsius. It is generally referred to as the heat capacity of gas and is also known as molar heat capacity when referred to in terms of moles of gas.

The ratio of the specific heats $\boldsymbol{\gamma = C_P/C_V}$ is a factor in adiabatic engine processes and in determining the speed of sound in a gas. This ratio $\gamma = 1.66$ for an ideal monoatomic gas and $\gamma = 1.4$ for air, which is predominantly a diatomic gas.

Gas	Specific heat capacity at constant pressure (J $kg^{-1}K^{-1}$)	Specific heat capacity at constant volume (J $kg^{-1}K^{-1}$)
Air	993	714
Argon	524	314
Carbon dioxide	834	640
Carbon monoxide	1050	748
Helium	5240	3157
Hydrogen	14300	10142
Nitrogen	1040	741
Oxygen	913	652
Water vapour	2020	-

Gas	C_v ($J\,K^{-1}\,mol^{-1}$)	C_p	$C_p - C_v$	γ
Monatomic gases				
He	12.5	20.8	8.33	1.67
Ar	12.5	20.8	8.33	1.67
Ne	12.7	20.8	8.12	1.64
Kr	12.3	20.8	8.49	1.69
Diatomic gases				
H_2	20.4	28.8	8.33	1.41
N_2	20.8	29.1	8.33	1.40
O_2	21.1	29.4	8.33	1.40
CO	21.0	29.3	8.33	1.40
Cl_2	25.7	34.7	8.96	1.35
Polyatomic gases				
CO_2	28.5	37.0	8.50	1.30
SO_2	32.4	40.4	9.00	1.29
H_2O	27.0	35.4	8.37	1.30

Work done by expanding gas

Steps for Calculating Work Done by an Expanding Gas

Step 1: Identify the pressure of the gas.

Step 2: Identify the change in the volume of the gas.

Step 3: Find work done by gas by substituting the values found in **steps 1 and 2** into the equation for pressure-volume work $W = p\Delta V$

Formulas for Calculating Work Done by an Expanding Gas

Pressure-volume work: When energy is added to gas molecules and increases their kinetic energy, the gas expands and does work on its surroundings. The work done by the gas with constant pressure can be found by: $W=p\Delta V$, where W is work, p is a pressure, and ΔV is the change in the volume of the gas.
When the volume of a gas changes from V_i to V_f, the change in the volume of the gas ΔV is $\Delta V=V_f-V_i$
Let's practice calculating work done by an expanding gas with the following two examples.

Example Problem 1 - Calculating Work Done by an Expanding Gas

A helium balloon is filled at a park with a gas pressure of 100kPa causes its volume to expand from 100cm3 to 300cm3. How much work is done by the gas on the rubber surface of the balloon?

Step 1: Identify the pressure of the gas.

The pressure of the gas is 100kPa.

Step 2: Identify the change in the volume of the gas.

The gas expands from its initial volume 100cm3 to its final volume 300cm3. Then, the change in the volume is:$\Delta V=V_f-V_i=300cm^3-100cm^3=200cm^3$

Step 3: Find work done by gas by substituting the values found in **steps 1 and 2** into the equation for pressure-volume work $W=p\Delta V$

Substituting 100kPa for p and 200cm3 for ΔV gives us: $W=p\Delta V=(100kPa)(200cm^3)=20{,}000kPa\cdot cm^3\times \frac{1J}{1000kPa\cdot cm^3}=20J$

The work done by the gas on the rubber surface of the balloon is 20J**.**

Example Problem 2 - Calculating Work Done by an Expanding Gas

A cylinder filled with gas is sealed by a piston. The gas is maintained at a constant pressure 50.0kPa while its volume increases from 25.0cm3 to 75.0cm3. How much work is done by the gas on the piston?

Step 1: Identify the pressure of the gas.

The pressure of a gas is 50.0kPa

Step 2: Identify the change in the volume of the gas.

The gas expands from its initial volume 25.0cm3 to its final volume 75.0cm3. Then, the change in the volume is:$\Delta V=V_f-V_i=75.0cm^3-25.0cm^3=50.0cm^3$

Step 3: Find work done by gas by substituting the values found in **steps 1 and 2** into the equation for pressure-volume work $W=p\Delta V$

Substituting 50.0kPa for p and 50.0cm3 for ΔV gives us:$W=p\Delta V=(50.0kPa)(50.0cm^3)=2500kPa\cdot cm^3\times \frac{1J}{1000kPa\cdot cm^3}=2.50J$

The work done by the gas on the piston is 2.50J**.**

Elasticity of a perfect gas

What is meant by adiabatic elasticity?

When the gas is compressed under conditions when no heat is allowed to enter or leave the system then it is called adiabatic elasticity.

What is meant by isothermal elasticity?

Isothermal elasticity is the type of elasticity that occurs when the gas is compressed in a way that the temperature is kept constant under isothermal conditions compared to the corresponding volume elasticity. This is denoted by K_T.