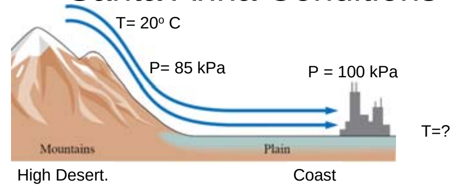
First Law of Thermodynamics
9.2

Thermodynamic processes
Cyclic processes
Molar specific heats.

Santa Anna Conditions



Santa Ana winds originate in the high desert region of California and is heated by adiabatic compression during the rapid descent to the coast. For the above conditions what would the temperature at the coast be?

Question

A 5.0 mol sample of an ideal gas with c_v =5/2R undergoes an expansion during which the gas does 5.1 kJ of work. If it absorbs 2.7 kJ of heat during this process, by how much does its temperature change?

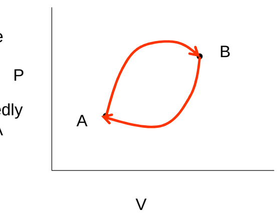
Question.

A gas with $\gamma = 5/3$ is at 450 K at the start of an expansion that triples its volume. The expansion is isothermal until the volume has doubled, then adiabatic the rest of the way. What is the final gas temperature?

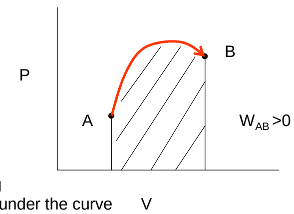
Cyclic processes

Cyclic processes form the basis for heat engines.

The system goes repeatedly from A to B and back to A

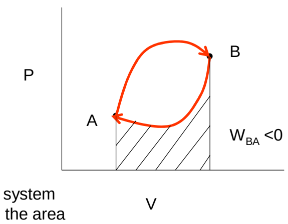


Cyclic processes



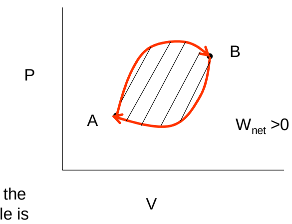
The work done in going from A to B is the area under the curve

Cyclic processes



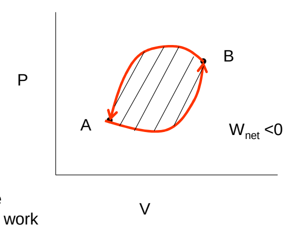
The work done on the system in going from B to A is the area under the curve.

Cyclic processes



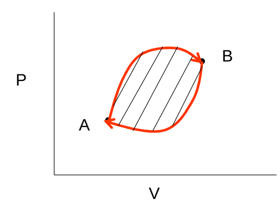
The net work done by the system during the cycle is the area under the curve.

Cyclic processes



If the cycle is run in the opposite direction, the work done by the system is negative.

Cyclic processes



The change in internal energy over one cycle is zero

$$\Delta U = 0$$

The work done by the system is equal to the total heat input.

Q = w

Question

A 25 L sample of an ideal gas with γ=1.67 is at 250K and 50 kPa. The gas is compressed adiabatically until its pressure triples, then cooled at constant volume back to 250 K, and finally allowed to expand isothermally to its original state. Sketch a PV diagram of the cycle. How much work is done by the gas?

Specific Heats of an Ideal Gas

Specific heat at constant volume.

The specific heat at constant volume for air

$$\gamma = 1.40 = \frac{c_P}{c_V} = \frac{c_V + R}{c_V}$$

$$c_V = \frac{R}{\gamma - 1} = \frac{R}{1.40 - 1} = 2.5R = \frac{5}{2}R$$

How do we explain this?

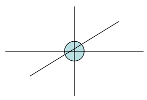
Kinetic Theory

Kinetic Energy of an Ideal Gas

Recall that the kinetic energy of an ideal gas was calculated to be

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

In this analysis we only considered the translation kinetic energy along the 3 perpendicular directions, x, y, z. Velocity along each direction is independent.
A kinetic energy of ½ kT is associated with each degree of freedom



Statistical Thermodynamics

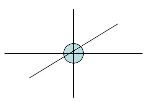
Degrees of Freedom – no. of coordinates needed to describe the kinetic properties of a gas molecule.

Equipartition Theorem

For a molecule at thermal equilibrium at temperature T, the average energy of a molecule is equal to the number of degrees of freedom times ½ kT.

Each degree of freedom is like a reservoir for thermal energy. The reservoirs are randomly filled to hold the same average energy.

Monatomic Gas



Degrees of Freedom

For a monatomic gas, such as He, Ar, the number of degrees of freedom per molecule is equal to 3, (for x, y, z)

Internal energy U

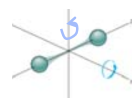
The internal energy U is equal to

$$U = \frac{3}{2}NkT = \frac{3}{2}nRT$$

molar specific heat at constant v, c_V

$$c_v = \frac{3}{2}R$$

Diatomic gas



For a diatomic gas, such a N_2 and O_2 which are the major constituents of air , each molecule has addition degrees of freedom.

Rotational degrees of freedom.

A diatomic molecule can rotate around the three mutually perpendicular axes, x, y, z.
However, the rotation around the x axis does not lead to any change in the molecule.
Thus, a diatomic molecule has 5 degrees of freedom, 3 translational and 2 rotational

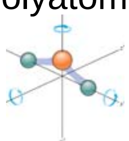
Specific Heat

The specific heat of a diatomic molecule is thus

$$c_V = \frac{5}{2}R$$

in agreement with c_V for air.

Polyatomic gas



Degrees of freedom

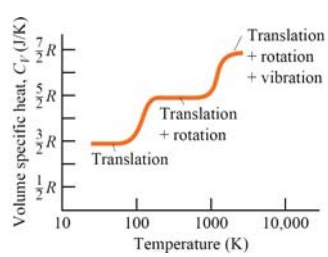
For a polyatomic gas, the rotation around all three perpendicular directions leads to distinguishable configurations. Thus the polyatomic gas molecule has 6 degrees of freedom

Specific heat.

The molar specific heat for a polyatomic gas molecule is

$$c_V = 3R$$

Quantum Effects



The specific heat c_V for H_2 gas depends on T. At low T the rotational energy reservoir is inaccessible.

Question

A gas mixture of 2.5 mol O_2 and 3.0 mol Ar. What is the molar specific heat at constant volume and pressure for this mixture?