

Thermal & Statistical Physics

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PHYS 343

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LECTURE 10



Exact and Inexact Differentials
Thermodynamic Systems
Free Expansion
First Law

FIRST LAW OF THERMODYNAMICS

Reversible Processes

Free Expansion

Mechanical Work

Exact and Inexact Differentials

A **state function** is a property that depends solely on the state of the system. It does not depend on how the system was brought to that state.

When a system is brought from an initial to a final state, the change in a state function is independent of the path followed.

An infinitesimal change of a state function is **an exact differential**.

Internal energy U : state function

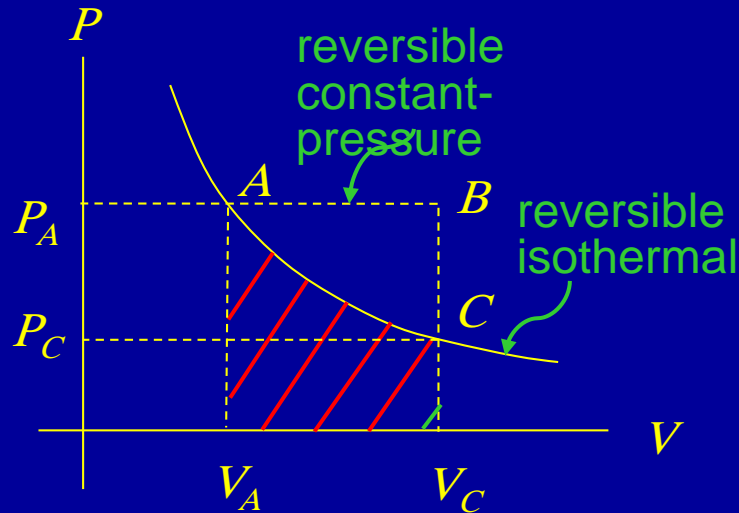
dU : exact differential

$$\int_i^f dU = U_f - U_i = \Delta U, \text{ independent of the path}$$

Work and heat are not state functions and do not correspond to exact differentials.

Of the three thermodynamic variables, only two are independent. It is convenient to choose V and T as the independent variables for U .

Work and Heat along Reversible Isothermal Expansion for an Ideal Gas, where $U=U(T)$



$$T_B = T_A \frac{V_C}{V_A}$$

$$w_{AC} = -nRT_A \ln \frac{V_C}{V_A}$$

$$w_{BC} = 0$$

$$w_{AB} = -P_A (V_B - V_A)$$

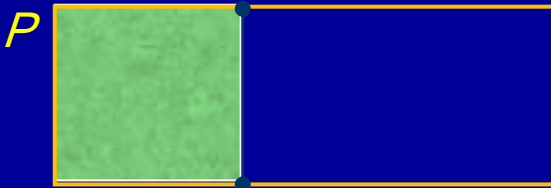
$$\Delta U_{AC} = 0 \Rightarrow q_{AC} = nRT_A \ln \frac{V_C}{V_A}$$

$$q_{BC} = \Delta U_{BC} = \int_{T_B}^{T_C} c_V dT$$

$$\Delta U_{AB} = \int_{T_A}^{T_B} c_V dT$$

$$q_{AB} = \Delta U_{AB} - w_{AB} = \int_{T_A}^{T_B} c_V dT + P_A (V_B - V_A)$$

Free Expansion



Suddenly remove the partition

No work, no heat! $\Delta U = 0$

$$dU = c_V dT + \left(\frac{\partial U}{\partial V} \right)_T dV$$

$$U = U(T) \Leftrightarrow \Delta T = 0$$

For real, non-ideal gases these hold approximately, and $\left(\frac{\partial U}{\partial V} \right)_T$ is small.

A process is called adiabatic if no heat is transferred to or out of the system.

$$\Delta U = w_{\text{ad}}, \quad dU = dw_{\text{ad}}$$

$$dU = c_V dT = -PdV$$

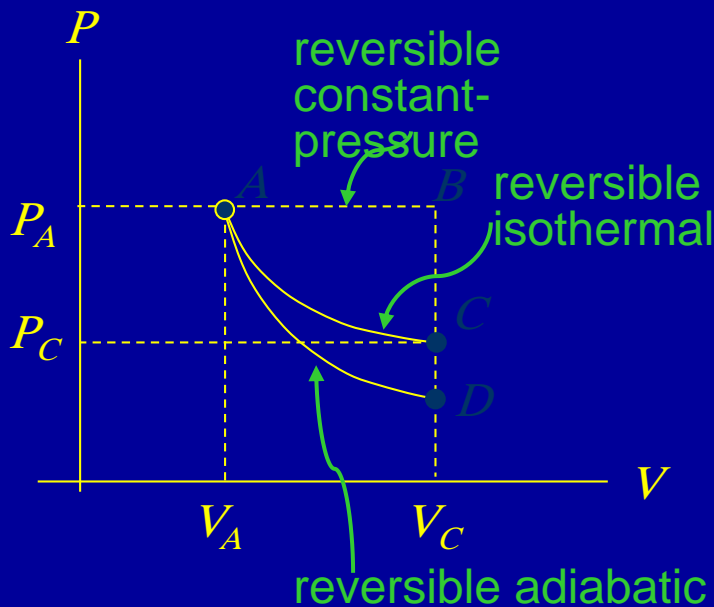
$$P = -\frac{nRT}{V} dV \quad (\text{ideal gas})$$

If $c_V(T)$ is known, this can be used to determine T (and thus also P) as a function of V .

For a monatomic ideal gas,

$$c_V = \frac{3}{2} nR \quad \text{independent of } T \Rightarrow$$

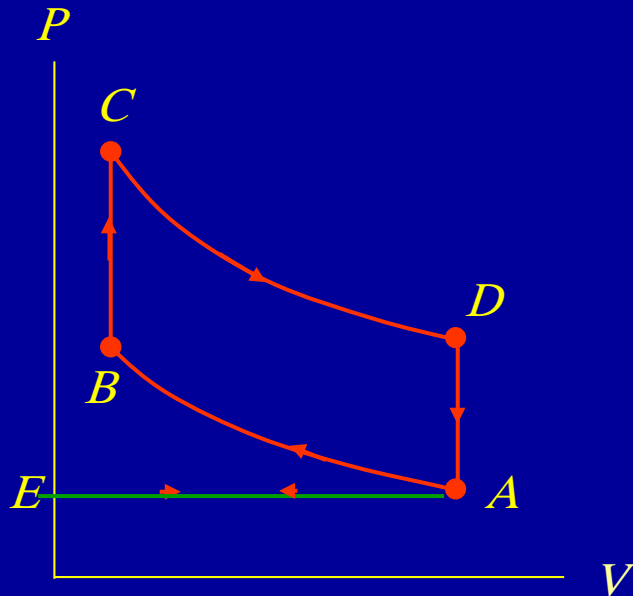
$$\left(\frac{T_D}{T_A} \right)^{\frac{3}{2}} = \frac{V_A}{V_D} \quad \text{Adiabatic cooling!}$$



Gases heat up when compressed adiabatically.

(This is why the pump used to inflate a tire becomes hot during pumping.)

Thermodynamics of the Otto Cycle



Reversible adiabatic compression AB: $T_A V_A^{\gamma-1} = T_B V_B^{\gamma-1}$

BC is reversible absorption of heat q_h from a series of reservoirs whose temperatures range from T_B to T_C :

$$q_h = \int_{T_B}^{T_C} c_V dT.$$

If we assume c_V is constant, $q_h = c_V (T_C - T_B)$.

Reversible adiabatic expansion CD: $T_C V_C^{\gamma-1} = T_D V_D^{\gamma-1}$ or $T_C V_B^{\gamma-1} = T_D V_A^{\gamma-1}$

DA is reversible rejection of heat q_c to a series of reservoirs whose temperatures range

from T_D to T_A : $q_c = \int_{T_D}^{T_A} c_V dT = -c_V (T_D - T_A)$.

$$\eta = 1 - \frac{|q_c|}{q_h} = 1 - \frac{T_D - T_A}{T_C - T_B} = 1 - \left(\frac{V_B}{V_A} \right)^{\gamma-1}$$

V_B / V_A : compression ratio