PHY 341/641 Thermodynamics and Statistical Mechanics
MWF: Online at 12 PM & FTF at 2 PM

Plan for Lecture 3:

Reading: Chapters 1.5-1.6

1. **Evaluation of work for various processes on an ideal gas**
2. **Evaluation of heat for various processes on an ideal gas**
3. **Internal energy and enthalpy**

In this lecture we will discuss the concepts and values of heat and work for various processes on ideal gases.

http://users.wfu.edu/natalie/s21phy341/homework/

PHY 341/641 Thermodynamics and Statistical Mechanics

MWF 12 and 2	Online and face-to-face	http://www.wfu.edu/~natalie/s21phy341/

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Course schedule for Spring 2021

(Preliminary schedule -- subject to frequent adjustment.) Reading assignments are for the **An Introduction to Thermal Physics** by Daniel V. Schroeder. The HW assignment numbers refer to problems in that text.

	Lecture date	Reading	Topic	HW	Due date
1	Wed: 01/27/2021	Chap. 1.1-1.3	Introduction and ideal gas equations	1.21	01/29/2021
2	Fri: 01/29/2021	Chap. 1.2-1.4	First law of thermodynamics	1.17	02/03/2021
3	Mon: 02/01/2021	Chap. 1.5-1.6	Work and heat for an ideal gas		
4	Wed: 02/03/2021				

There is no new homework for this lecture.

Basic equations

General principle – expected of all systems
Follows from notion that we can/should account for all energy

First "law" of thermodynamics

$$\Delta U = Q + W$$

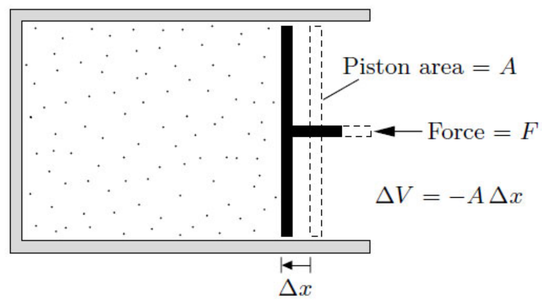
Special for an ideal gas system –
Equation of state $PV = Nk_BT$

Internal energy $U = \frac{1}{\gamma - 1} Nk_BT$

Review of basic equations needed here.

Calculation of work for various processes

Figure 1.8. When the piston moves inward, the volume of the gas changes by ΔV (a negative amount) and the work done on the gas (assuming quasistatic compression) is $-P\Delta V$. Copyright ©2000, Addison-Wesley.



$$W = -P\Delta V$$

Note that in our definition of work, the system contracts.

Expression for work.

Work for various processes for an ideal gas

$$W = -P\Delta V \qquad PV = Nk_B T$$

	Initial	Final	*W*
Constant *V*	$P_1 \quad V_1$	$P_2 \quad V_1$	**0**
Constant *P*	$P_1 \quad V_1$	$P_1 \quad V_2$	$-P_1(V_2-V_1)$

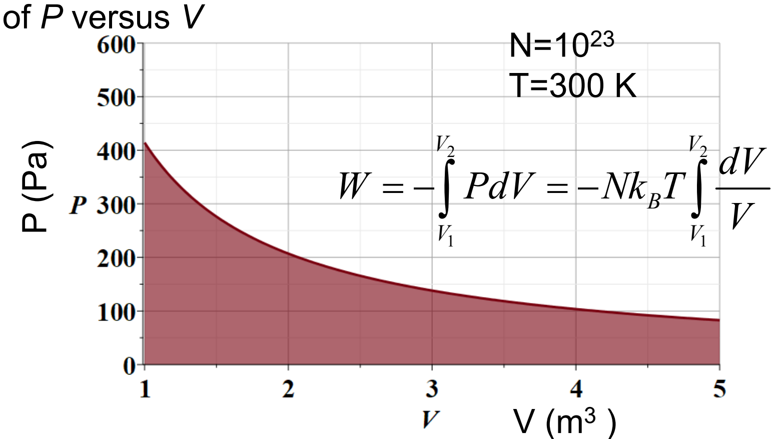
Summary of results for simple cases.

Work for various processes for an ideal gas

$$W = -P\Delta V \qquad PV = Nk_BT$$

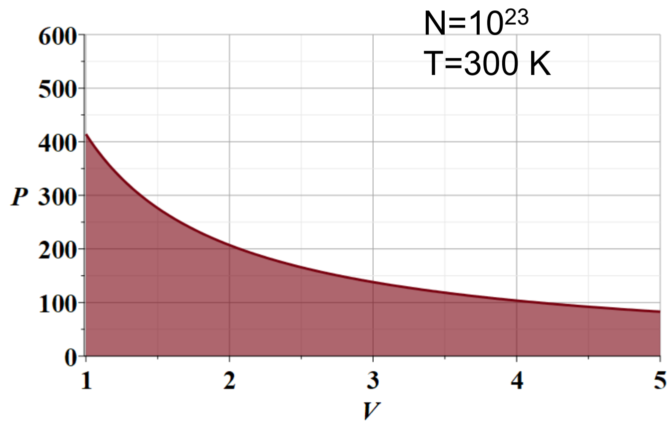
Now consider an isothermal process

In order to evaluate *W*, it is useful to consider a plot of *P* versus *V*



Work for an isothermal process.

Work for an isothermal process in an ideal gas



$$W = -\int_{V_1}^{V_2} P dV = -Nk_B T \int_{V_1}^{V_2} \frac{dV}{V} = -Nk_B T \ln\left(\frac{V_2}{V_1}\right)$$

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Performing the integral to evaluate work for an isothermal process.

Summary of results

	Initial	Final	*W*
Constant *V*	P_1 V_1	P_2 V_1	0
Constant *P*	P_1 V_1	P_1 V_2	$-P_1(V_2-V_1)$
Constant *T*	P_1 V_1	P_1V_1/V_2 V_2	$-P_1V_1 \ln(V_2/V_1)$

Updating the summary of results.

Now consider the effects of heat on the system

First "law" of thermodynamics

$$\Delta U = Q + W$$

Special for an ideal gas system –

Equation of state $PV = Nk_BT$

Internal energy $U = \frac{1}{\gamma - 1} Nk_BT$

Now consider heat for these and other processes.

Consider the ideal gas processes that we have just discussed:

First "law" of thermodynamics

$$\Delta U = Q + W$$

Con.	Initial	Final	*W*	*ΔU*	Q
V	$P_1 \quad V_1$	$P_2 \quad V_1$	0	$\frac{V_1(P_2 - P_1)}{\gamma - 1}$	ΔU
P	$P_1 \quad V_1$	$P_1 \quad V_2$	$-P_1(V_2 - V_1)$	$\frac{P_1(V_2 - V_1)}{\gamma - 1}$	$\Delta U - W$
T	$P_1 \quad V_1$	$P_1V_1/V_2 \quad V_2$	$-P_1V_1 \ln(V_2/V_1)$	0	$-W$

Combining work and heat results while considering change in internal energy for the same processes.

Now consider the case where Q=0, termed an “adiabatic” process for a system described by an ideal gas equation of state.

$$PV = Nk_BT$$

$$U = \frac{Nk_BT}{\gamma - 1} = \frac{PV}{\gamma - 1}$$

$$\Delta U = Q + W \quad \Rightarrow \quad \Delta U = W = -P\Delta V$$

$$\Delta U = \frac{\Delta PV + P\Delta V}{\gamma - 1} = -P\Delta V$$

$$\Rightarrow \Delta PV = -\gamma P\Delta V \qquad \text{Infinitessimal form } \frac{dP}{P} = -\gamma \frac{dV}{V}$$

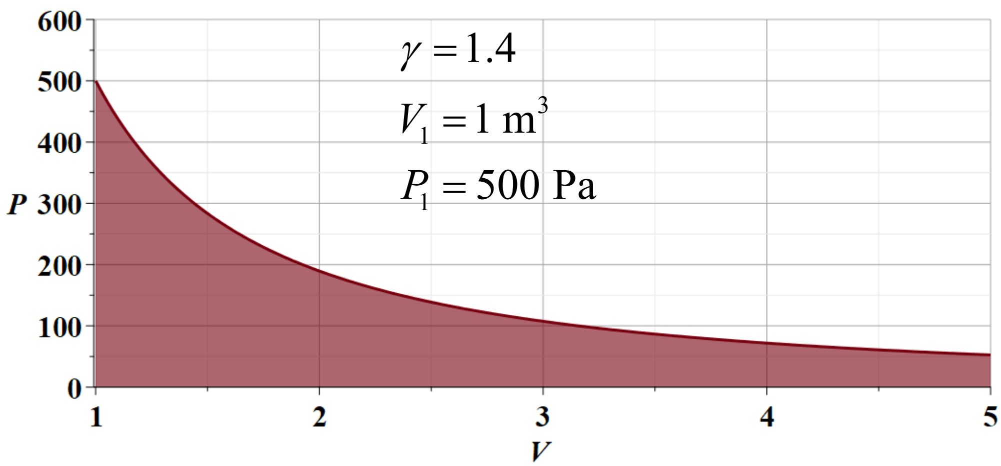
$$\Rightarrow d \ln P = -\gamma d \ln V = -d \ln V^{\gamma} \qquad d \ln(PV^{\gamma}) = 0$$

$$PV^{\gamma} = \text{constant} \qquad \text{Also } VT^{1/(\gamma-1)} = \text{constant}$$

Now consider the situation when there is no heat added to the system. For the ideal gas, this leads to a modified equation of state in this case.

Work during an adiabatic process

$$W = -P_1V_1^{\gamma}\int_{V_1}^{V_2}\frac{dV}{V^{\gamma}} = -\frac{P_1V_1}{\gamma-1}\left(1-\left(\frac{V_1}{V_2}\right)^{\gamma-1}\right)$$



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Graph of adiabatic ideal gas equation of state and work integral.

The notion of heat capacity

The rate of heat increment per increment of temperature

$C = \frac{dQ}{dT}$ depends on the process

Constant volume process

$$C_V = \left.\frac{dQ}{dT}\right|_V = \frac{d}{dT}\left(\frac{Nk_B T}{\gamma - 1}\right) = \frac{Nk_B}{\gamma - 1}$$

Note that g is temperature dependent, but it that contribution is generally a small correction.

Specific heat.

Constant pressure process

$$C_P = \left.\frac{dQ}{dT}\right|_P = \frac{d}{dT}\left(\frac{Nk_BT}{\gamma-1}+PV\right)$$

$$= \frac{Nk_B}{\gamma-1} + Nk_B = \frac{\gamma Nk_B}{\gamma-1}$$

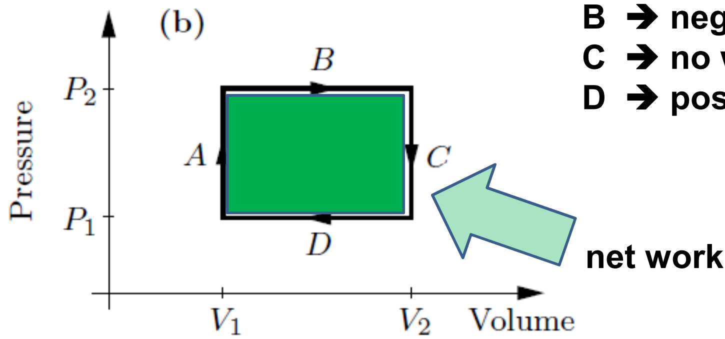
Note that, as previously suggested --

$$\frac{C_P}{C_V} = \gamma$$

Specific heat at constant pressure.

Net work done in a cyclic process

Consider the following 4 step cycle



A ➔ no work
B ➔ **negative work**
C ➔ **no work**
D ➔ **positive work**

$$W_{ABCD} = -(P_2 - P_1)(V_2 - V_1)$$

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Consider a set of processes that return the system to its beginning conditions – a complete cycle.

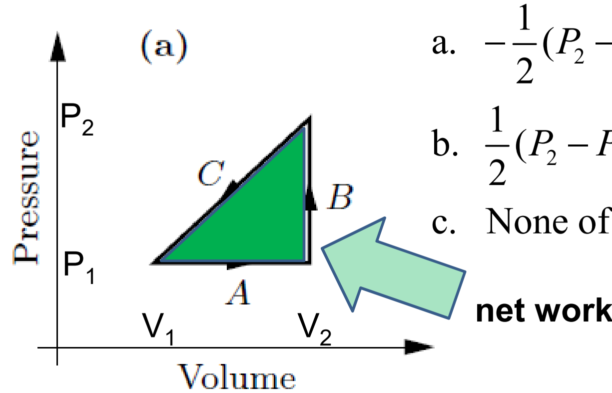
Net work done in a cyclic process -- continued
Consider the following 3 step cycle:

Which of the following represent the net work W_{ABC}?

a. $-\frac{1}{2}(P_2 - P_1)(V_2 - V_1)$

b. $\frac{1}{2}(P_2 - P_1)(V_2 - V_1)$

c. None of these



Another example of a complete cycle.

Question – What is ΔU for full cycle process?

We saw examples of complete cycles with net work and net heat. What about the net change in internal energy?