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

Class notes for Lecture 4: Review of energy, heat, and work

Reading: Chapters 1.1-1.6

- 1. Your questions
- 2. Basic concepts in thermal physics
- 3. Special results for an ideal gas
- 4. Examples

Online Colloquium: "ALIX in Wonderland: Multivalency, Phosphorylation-mediated Amyloids, Autoinhibition, and Endosomal Membrane Interactions" — February 4, 2021 at 4 PM

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Thursday, February 4, 2021 4:00 PM EST

Via Video Conference (contact wfuphys@wfu.edu for link information)

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	Торіс	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	Chap. 1.1-1.6	Review of energy, heat, and work	1.45	02/05/2021	
5	Fri: 02/05/2021	Chap. 2.1				
6	Mon: 02/08/2021					

Spring 2021 Schedule for <u>N. A. W. Holzwarth</u>

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00-10:00	Lecture Preparation	PHY712 Discussions	Lecture Preparation		Lecture Preparation
10:00-11:00	Electrodynamics	PHY341/641	Electrodynamics		Electrodynamics
	PHY712	Discussions	PHY712	Physics Research	PHY712
11:00-12:00	Lecture Preparation		Lecture Preparation		Lecture Preparation
12:00-12:30	Thermo & SM		Thermo & SM		Thermo & SM
12:30-1:00	PHY341/641		PHY341/641	Condensed Matter	PHY341/641
1:00-2:00	Office hours	Physics	Office hours	Journal Club	Office hours
2:00-3:00	Thermo & SM	Research	Thermo & SM		Thermo & SM
	PHY341/641		PHY341/641	Physics Research	PHY341/641
3:00-4:00	Physics Research		Physics Research		
4:00-5:00				Physics	Physics Research
				Colloquium	

Additional schedule items

• One-on-one PHY 712 and 341/641 meetings -- 0.5 hr

Your questions

From Kristen – 1.In lecture 2, on slides 11 and 12, we discussed the pressure on the piston. Could you explain why we still need to incorporate the 1/3 into the equation when we are already accounting for the average translational velocity? I thought the 1/3 was applied to just the velocity in the x direction to account for all the directions. 2. I am also still a bit confused about the applications of the equipartition theorem, if you could clarify what we need to know about it that would be helpful. From Parker -- Why is temperature thought of as the ability of an object to quickly give up energy, why is this true and not the definition of temperature? From Michael -- My question regarding unit one's information is this: I am still confused how we determined that the net work done in the cyclic process for the rectangle was negative while the example with the triangle example was positive. Is this because more work must be done at a higher pressure in comparison to a lower pressure? It looks to me that for the rectangle example, the net work would be zero since you have both +W and -W cancelling each other out. From Annelise -- Can we review more about what enthalpy is and why it is important? In the table from the notes can we go over why the Work for Constant

Volume is 0, why the internal energy for constant temperature is 0?

From Rich -- what does it mean when there are fractional degrees of freedom like for benzene?

From Noah --How well does the Dulong Petit rule actually describe heat capacity for a solid, and for what types of materials does it fail? From Zezhong -- Why the work done process should be cyclic and what is the mathematical procedure to deduce the internal energy formula? **Question** -- In lecture 2, on slides 11 and 12, we discussed the pressure on the piston. Could you explain why we still need to incorporate the 1/3 into the equation when we are already accounting for the average translational velocity? I thought the 1/3 was applied to just the velocity in the x direction to account for all the directions.



Figure 1.4. A greatly simplified model of an ideal gas, with just one molecule bouncing around elastically. Copyright ©2000, Addison-Wesley.

 $\Rightarrow \langle v_x^2 \rangle = \frac{1}{3} \langle v^2 \rangle$

Pressure on piston from one collision $P = \frac{F_x}{A} \approx m \frac{\Delta v_x}{\Delta t} \frac{1}{A} \approx m \frac{2v_x}{2L/v_x} \frac{1}{A} = \frac{mv_x^2}{V} \Longrightarrow \frac{m\left\langle v_x^2 \right\rangle}{V}$ averaged over particles Note that $v^2 = v_x^2 + v_y^2 + v_z^2$

Also note
$$\langle v_x^2 \rangle = \langle v_y^2 \rangle = \langle v_z^2 \rangle$$

Question -- I am also still a bit confused about the applications of the equipartition theorem, if you could clarify what we need to know about it that would be helpful.

Comment – This deals with how we can model the temperature dependence of the internal energy of an ideal gas. For example, we can measure the heat capacity of a real gas. At constant volume $\Delta U=Q$ so that $C_V=d \Delta U/dT$



Figure 1.13. Heat capacity at constant volume of one mole of hydrogen (H₂) gas. Note that the temperature scale is logarithmic. Below about 100 K only the three translational degrees of freedom are active. Around room temperature the two rotational degrees of freedom are active as well. Above 1000 K the two vibrational degrees of freedom also become active. At atmospheric pressure, hydrogen liquefies at 20 K and begins to dissociate at about 2000 K. Data from Woolley et al. (1948).

2/03/2021

Question -- Why is temperature thought of as the ability of an object to quickly give up energy, why is this true and not the definition of temperature?

Comment – I have no idea....

Question -- I am still confused how we determined that the net work done in the cyclic process for the rectangle was negative while the example with the triangle example was positive. Is this because more work must be done at a higher pressure in comparison to a lower pressure? It looks to me that for the rectangle example, the net work would be zero since you have both +W and -W cancelling each other out.





Question -- Can we review more about what enthalpy is and why it is important?

Comment -- U and H are two thermodynamic energies that we will discuss. Additionally, we will discuss the Helmholtz free energy F and the Gibbs free energy G. These differ in what are their "natural" variables.

Question -- In the table from the notes can we go over why the Work for Constant Volume is 0,

Integral relation --

$$W = -\int_{V_1}^{V_2} P(V) dV$$

Note that
$$W = 0$$
 when $V_1 = V_2$.

Example -- Work for an isothermal process in an ideal gas



Question -- How well does the Dulong Petit rule actually describe heat capacity for a solid, and for what types of materials does it fail?

Comment – the "rule of Dulong and Petit" suggests that the molar heat capacity at constant volume should be

 $C_V = 3R$

Rule is often not obeyed.....



Figure 1.14. Measured heat capacities at constant pressure (data points) for one mole each of three different elemental solids. The solid curves show the heat capacity at constant *volume* predicted by the model used in Section 7.5, with the horizontal scale chosen to best fit the data for each substance. At sufficiently high temperatures, C_V for each material approaches the value 3R predicted by the equipartition theorem. The discrepancies between the data and the solid curves at high T are mostly due to the differences between C_P and C_V . At T = 0 all degrees of freedom are frozen out, so both C_P and C_V go to zero. Data from Y. S. Touloukian, ed., Thermophysical Properties of Matter (Plenum, New York, 1970). Copyright ©2000, Addison-Wesley.

Fundamental relationships – true in principle for all materials.

First "law" of thermodynamics $\Delta U = Q + W$

Definition of mechanical work. $W = -P\Delta V$

Definition heat capacity.

$$C = \frac{dQ}{dT}$$

General concepts - continued -

Equilibrium – in fact, we will be mostly be studying equilibrium thermodynamics. It perhaps would be more honest to call our study thermostatics. Dynamic processes, such as those involving flow and time dependent processes, involve additional considerations.

Which of these situations are approximately equilibrium systems?

- a. A student
- b. An instructor
- c. Soup in a bowl
- d. Water in a cup
- e. Liquid nitrogen in an insulated tank

Mathematical representation -

Thermodynamics involves a lot of functions and a lot of variables which can be nicely modeled using concepts of multivariable functions. Here we need to use the concept of partial derivatives and total derivatives.

Suppose that we have a function f which has variables q and p and t. In turn, q = q(t) and p = p(t). If we know that f = f(q, p, t), the

total differential is given by
$$df = \left(\frac{\partial f}{\partial q}\right)_{p,t} dq + \left(\frac{\partial f}{\partial p}\right)_{q,t} dp + \left(\frac{\partial f}{\partial t}\right)_{q,p} dt$$

For example, the total derivative with respect to time is

$$\frac{df}{dt} = \left(\frac{\partial f}{\partial q}\right)_{p,t} \frac{dq}{dt} + \left(\frac{\partial f}{\partial p}\right)_{q,t} \frac{dp}{dt} + \left(\frac{\partial f}{\partial t}\right)_{q,p}$$

Example

 $f(q, p, t) = qp^{2}t^{3}$ where $q(t) = e^{-t}$ $p(t) = e^{-2t}$ Evaluate $\frac{df}{dt}$ in two ways, using partial derivatives and after direct substitution. Do you get the same answer?

Special relationships for an ideal gas
Equation of state

$$PV = Nk_BT = nRT$$

Internal energy for ideal gas
 $U = \frac{Nk_BT}{\gamma - 1} = \frac{nRT}{\gamma - 1} = \frac{PV}{\gamma - 1}$ $\gamma = \frac{C_P}{C_V}$

Equation of state for ideal gas in an adiabatic process: $PV^{\gamma} = \text{constant}$ Also $VT^{1/(\gamma-1)} = \text{constant}$ Example –

Problem 1.37. In a Diesel engine, atmospheric air is quickly compressed to about 1/20 of its original volume. Estimate the temperature of the air after compression and explain why a Diesel engine does not require spark plugs.

Equation of state for ideal gas in an adiabatic process:

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

$$V_1 T_1^{1/(\gamma-1)} = V_2 T_2^{1/(\gamma-1)} \qquad \text{If } T_1 = 300 \text{ K, what}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{(\gamma-1)} = 20^{(\gamma-1)} \approx 3.3 \qquad \text{If } T_2?$$
Hotter than boiling water?

(assuming $\gamma = 1.4$)

What would be the pressure in this case after the compression?

$$\frac{P_1 V_1^{\gamma}}{P_2} = \frac{P_2 V_2^{\gamma}}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = 20^{1.4} = 66.29$$