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

Plan for Lecture 1:

Reading: Chapters 1.1-1.3

1. **Course structure and expectations**
2. **Some motivation and history**
3. **Temperature**
4. **Ideal gas equation of state**

Physics Colloquium series – Thursdays 4-5 PM online

SEMINARS-2021-SPRING

WFU Physics Colloquium Schedule — Spring 2021

Previous and future colloquia

All colloquia will be held at 4 PM online (unless noted otherwise).

Thurs. Jan. 28, 2021 — Professor George C. Schatz, Northwestern University — "Plasmonic Lattices" (host: J. Macosko)

Thurs. Feb. 04, 2021 — Professor Lalit Deshmukh, University of California, San Diego –"ALIX in Wonderland: Multivalency, Phosphorylation-mediated Amyloids, Autoinhibition, and Endosomal Membrane Interactions" (host: S. Cho)

Thurs. Feb. 11, 2021 — Professor Carolyn Bertozzi, Stanford University — "Therapeutic Opportunities in Glycoscience" (host: J. Macosko) http://users.wfu.edu/natalie/s21phy341/

PHY 341/641 Thermodynamics and Statistical Mechanics

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

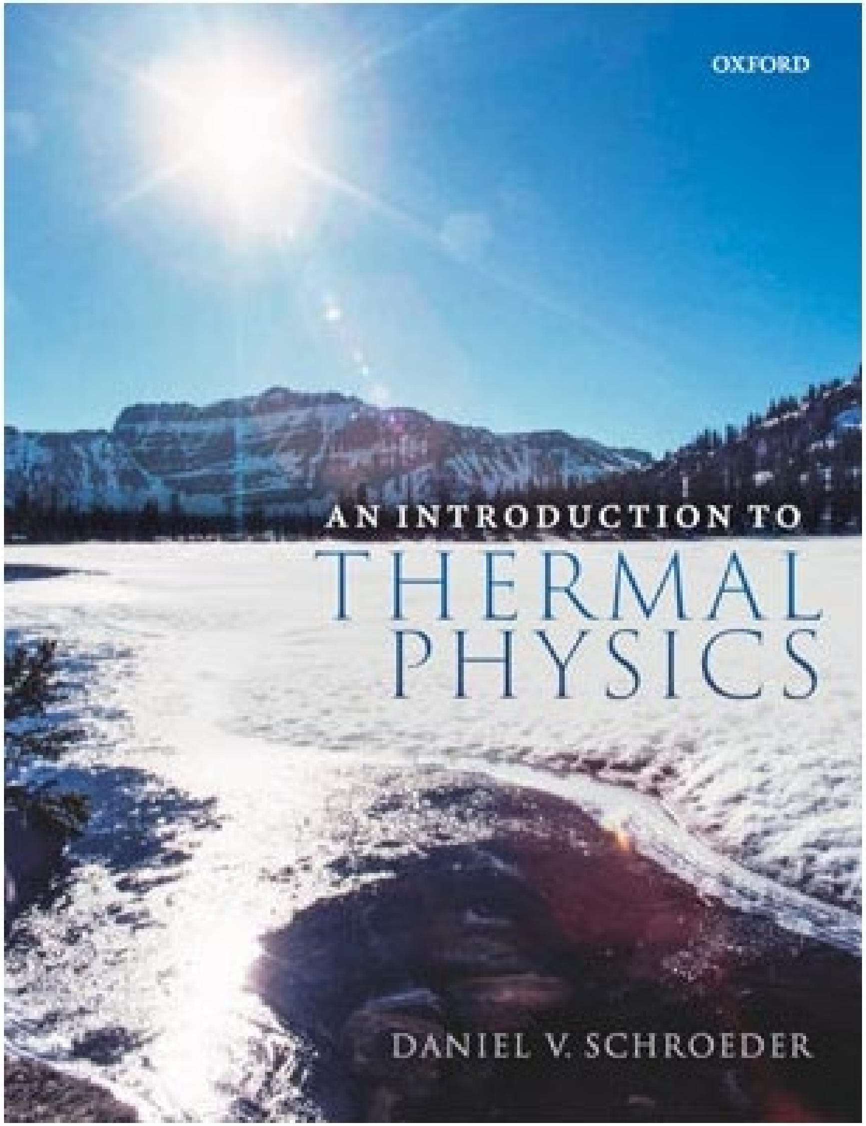
Instructor: Natalie Holzwarth	**Office:**300 OPL	**e-mail:**natalie@wfu.edu

---

- General information
- Syllabus and homework assignments
- Lecture notes

Last modfied: Sunday, 24-Jan-2021 22:58:27 EST

Textbook



author's web page:

http://physics.weber.edu/thermal/

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

General Information

This course is a one semester survey of Thermodynamics and Statistical Mechanics, using the textbook: **An Introduction to Thermal Physics**, by Daniel V. Schroeder (Addison Wesley, 2000 and now Oxford University Press). The author and publishers have set up a very nice website for errata and additional information -- http://physics.weber.edu/thermal/.

Adapting to the challenges of these unprecedented times, this course has two sections -- A is online while B is face to face. Students can choose either section, adjusting to the best recommendations for healthy practices. The course will consist of the following components:

- Synchronous online meetings MWF 12-12:50 AM for section A (local time in Winston-Salem, NC, USA). These sessions will be recorded and posted on a password protected Google folder. Information on WFU Policy on Recordings. Synchronous face to face meetings MWF 2-2:50 in Olin 101 for section B. The class meetings will focus on discussion of the material, particularly answering your prepared and spontaneous questions.
- Asynchronous review of annotated lecture notes and corresponding textbook sections. The reading assignment and annotated lecture notes will be available one day before the corresponding synchronous online discussion. For each class meeting, students will be expected to submit (by email) at least one question for class discussion at least 3 hours before the earliest class time.
- Homework sets. Typically there will be one homework problem associated with each MWF class meeting.
- There will be two take-home exams, one at mid-term and the other during finals week.
- For PHY 641 students, there will be one project on a chosen topic related to thermal physics.
- There will be weekly one-on-one meetings of each student with the instructor to discuss the course material, homework, and/or projects. These may be face-to-face or online as appropriate.

Links to WFU pandemic policies – Since this class is online, however, it is possible that some of the one-on-one meetings can be face-to-face.

Wake Forest University's Standard Operating Procedure for Class Sessions Following Public Health Guidance (Policy 2.A.02). This is an updated version of our policies and procedures. Please note the clarification on our masking requirement for classes regardless of location (indoors or outdoors), a revision that makes this policy consistent with our current University masking policy.

Spring 2021 College COVID-19 Classrooms FAQs and Syllabus Statement. As in the fall, the Office of the Dean of the College expects the Spring 2021 COVID-19 Syllabus Statement to be on syllabi for any classes taught in-person (face to face or blended) to communicate clear expectations around masking, physical distancing, and illness from the very first day of class. Our COVID-19 Classroom FAQs includes classroom cleaning protocols; guidance on how to reserve space for out-of-class academic activities like masked and physically distanced office hours, small group workshops, film screenings, and language conversation hours through DeaconSpace; and assistance for anyone teaching in a less familiar space this semester.

It is likely that your grade for the course will depend upon the following factors:

Class participation	20%
Problem sets*	40%
Exams & Project	40%

*In general, there will a new assignment after each lecture, so that for optimal learning, it would be best to complete each assignment before the next scheduled lecture. According to the honor system, all work submitted for grading purposes should represent the student's own best efforts.

➔ Schedule weekly one-on-one meetings (or could meet with small groups if preferred.

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

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				
3	Mon: 02/01/2021				
4	Wed: 02/03/2021				
5	Fri: 02/05/2021	Chap. 2.1			
19	Wed: 03/10/2021				
20	Fri: 03/12/2021	Chap. 1-4	Review		
	Mon: 03/15/2021	No class	*APS March Meeting*	Take Home Exam	
	Wed: 03/17/2021	No class	*APS March Meeting*	Take Home Exam	
	Fri: 03/19/2021	No class	*APS March Meeting*	Take Home Exam	
21	Mon: 03/22/2021	Chap. 5.1			
22	Wed: 03/24/2021				

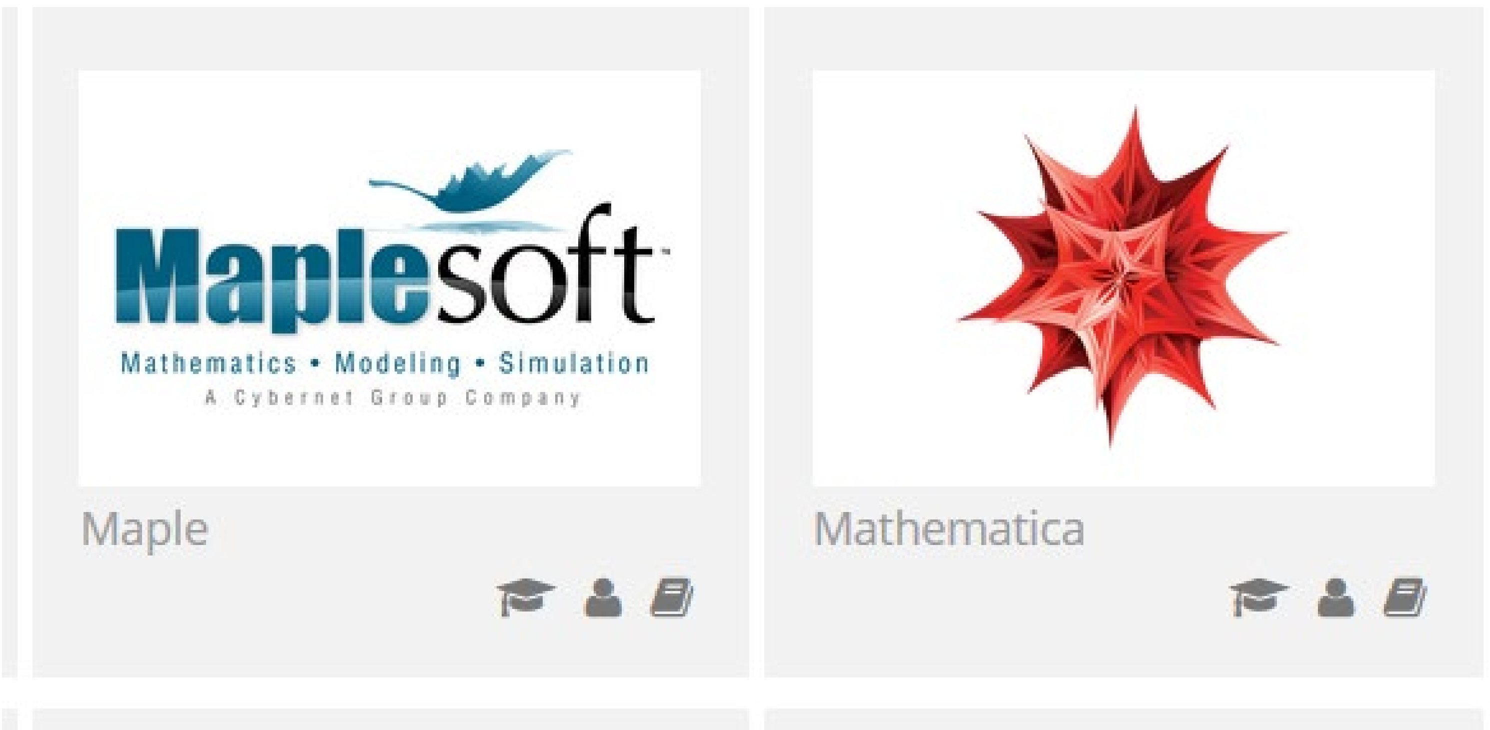
How to turn in your homework?

- Students on campus can turn in your homework to my mailbox. (Please clearly mark which class and HW # and your name.)
- Otherwise, students can turn in their work as a pdf file from algebraic manipulation software or from photographed or scanned paper. Also please clearly mark which class and HW & and your name.

Note if you want to collaborate on your homework with your (socially distanced) colleagues, that is fine. **Active collaboration is encouraged.** (Of course, the take home exams must be your own work.)

Comment – for some homework problems, you may wish to use algebraic manipulation software and VPN --

https://software.wfu.edu/audience/students/



Your questions –

Michael --My question regarding the class design is this: On the class website it states that the problem sets for the class are to represent our own best efforts, so does this mean that we as students should not collaborate with other students on these problem sets? Even if we are really stuck on a certain problem/topic are we not supposed to reach out to other students to bounce ideas off each other? If so, what would be the best way to resolve some of the confusion that may arise with certain problem sets?

Chao --Is there any relations between the number of atoms composing the molecules and the molecules' degrees of freedom? How does f=6 for atoms in crystalline solid being derived?
Can we derive a formula for thermal energy of diatomic gas in class?

Rich -- -Is there any theoretical definition or practical use for temperature in a single dimension (ie Tx, Ty, Tz) ? Why is rotation down the length of a diatomic molecules not considered?

Kristen -- After doing the assigned reading I would love to discuss why it is that many of the equations of thermodynamics are correct only when measured on the kelvin scale. Additionally, in the text specifically with Equation 1.17, the term translational kinetic energy is used, I was hoping you could clarify how this is different from simple kinetic energy.

Parker --And as the book states instead of PV=NRT, do you recommend we remember the conversion factor nR=Nk? What is the reason for this?

Annelise --how come in the average pressure equation we only take into consideration the velocity in the x direction? I see that in the next theorem about kinetic energy we can conclude that the y, z, and x equations are all equal- is this true for the pressure equation as well?

Leon --My question for tomorrow's lecture material focus on degrees of freedom. I still have a blurred definition of it. I first thought it's like coordinates and then find it wrong. So is it defined like all possible forms of energy a molecule could have? And how to know the exact number of df for different molecules.

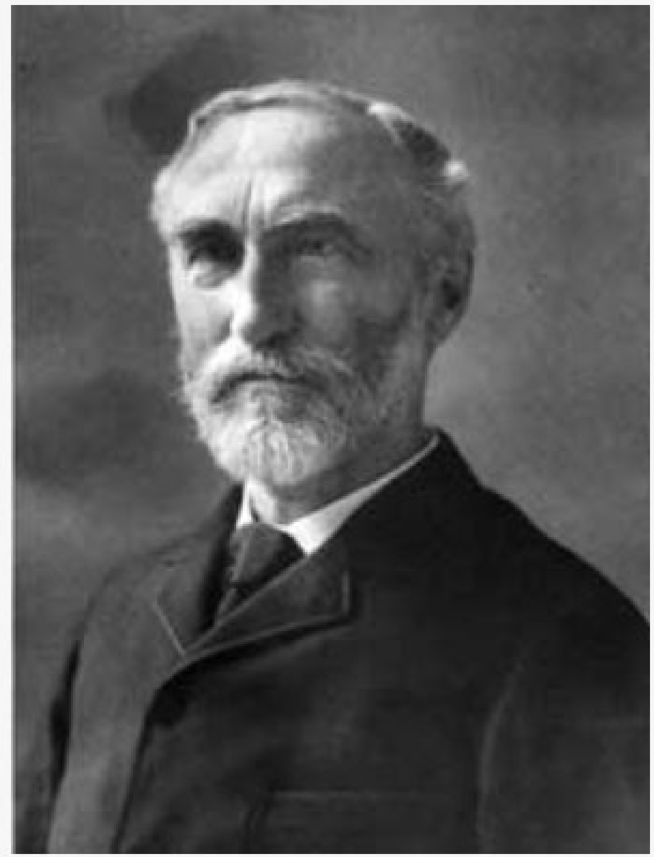
Noah -- One of the footnotes says that a decrease in the temperature by a factor of e is a more precise definition. Why is this?
2. I am curious to learn more about how some vibrational degrees of freedom do not contribute to temperature, and what types of modes these would be.

Giants of thermodynamics and statistical mechanics

Ludwig Boltzmann
1844-1906

Ludwig Boltzmann (1844–1906)

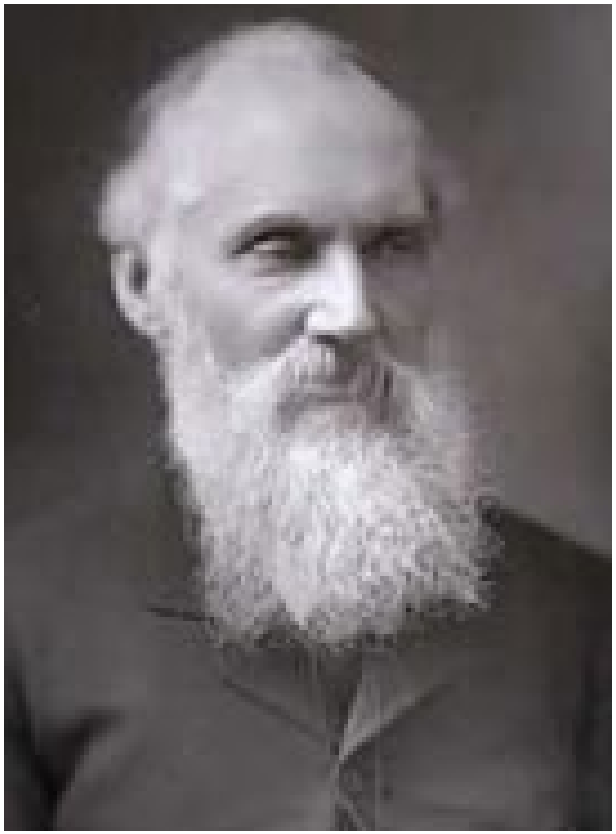
Josiah Willard Gibbs
1839-1903



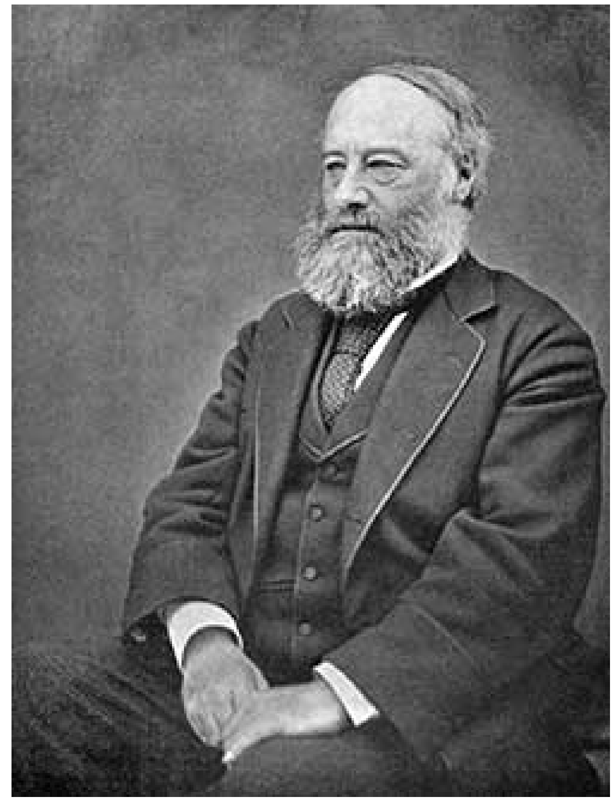
Josiah Willard Gibbs

Giants of thermodynamics and statistical mechanics -- continued

Sir William Thomson
(Lord Kelvin) 1824-1907



James Prescott Joule
1818-1889

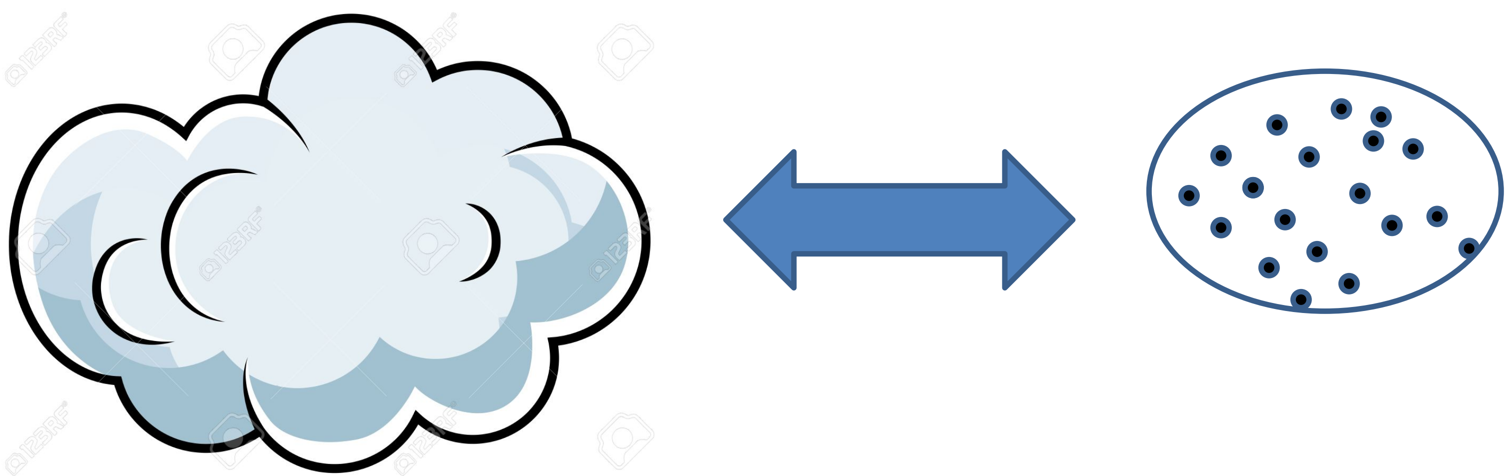


Note – it is not necessary to have a beard to study thermal physics.

What are we studying?

Thermodynamics is generally the study of heat and other forms of energy (work, mechanical, electrical, chemical, nuclear, etc.) typically measured in a macroscopic sample.

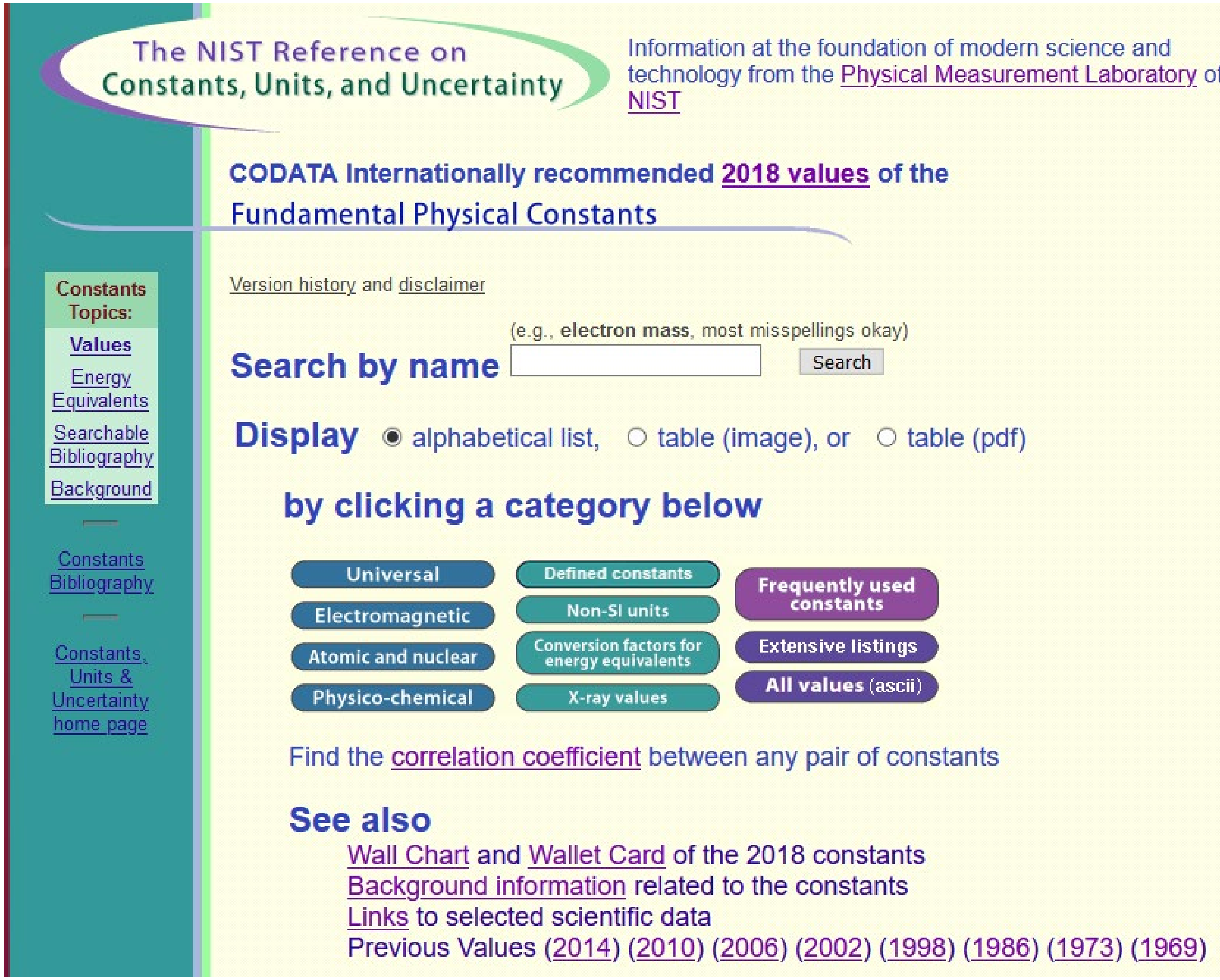
Statistical mechanics is the study of samples at the atomic level, attempting to reconcile the energetics at the atomic and macroscopic scales.



Useful concepts and quantities of thermodynamics

- ❑ 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.
- ❑ Temperature – $T \geq 0$ in Kelvin scale
- ❑ Volume – V in units of m^3
- ❑ Pressure – P in units of Pascals (Newtons/m^2) (Note that 1 atmosphere = 101325 Pascals (as defined))
- ❑ Mass – M in units of kg
- ❑ Number of particles -- N
- ❑ Energy – E or U in units of Joules

Reliable source for physical constants and unit conversions
https://physics.nist.gov/cuu/Constants/index.html



Note that, for a given system, the variables, P,V,N,T,E… are not independent. For a given materials, the specific relationship is often called the equation of state. For most materials this “equation of state” is very complicated. For most of this course we will use as a convenient and often useful materials system – the ideal gas. An ideal gas is a simplification of the behavior real gases (such as air) at low density described by the famous equation of state:

$$PV = Nk_B T$$

$$k_B \equiv \text{Boltzmann's constant}$$

$$\mathbf{1.380649 \ x10^{-23} J\ K^{-1}}$$

Where did the ideal gas equation of state come from?

a. It follows from first principles
b. It comes from observation
c. I never learned about this

Microscopic analysis of ideal gas equation of state.

$$PV = Nk_BT$$

Figure from your textbook:

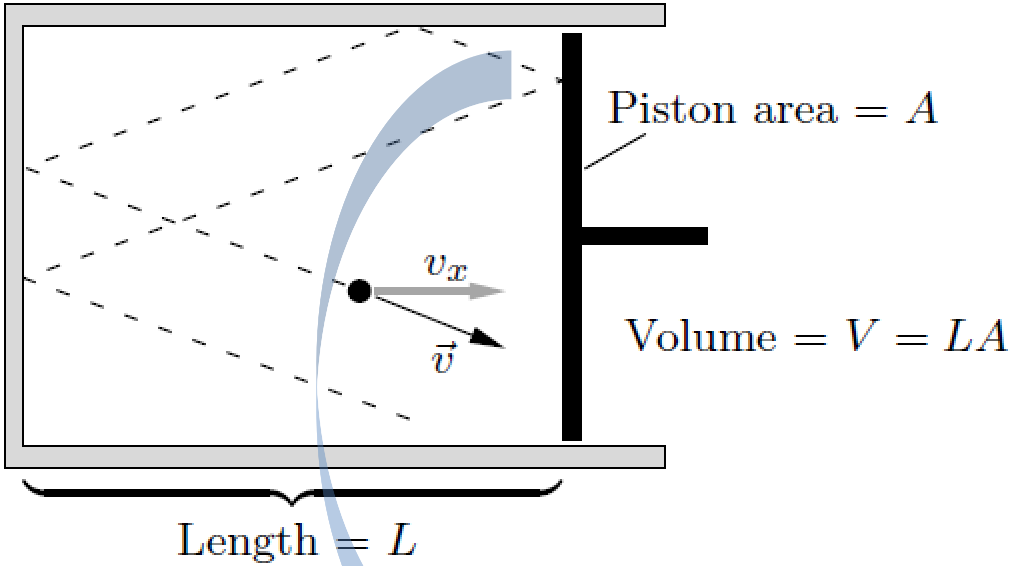


Figure 1.4. A greatly simplified model of an ideal gas, with just one molecule bouncing around elastically. Copyright ©2000, Addison-Wesley.

Collision of atom with piston exerts pressure

Pressure on piston from one collision

$$P = \frac{F_x}{A} \approx m\frac{\Delta v_x}{\Delta t}\frac{1}{A} \approx m\frac{2v_x}{2L/v_x}\frac{1}{A} = \frac{mv_x^2}{V}$$

For an ideal gas, we expect that

$$v_x^2 = v_y^2 = v_z^2 = \frac{1}{3}(v_x^2 + v_y^2 + v_z^2) \equiv \frac{1}{3}v^2$$

Here v is the magnitude of the translational velocity.

Pressure due to N particles colliding with piston:

$$P = \frac{N}{3V}mv^2$$

$$P = \frac{N}{3V} mv^2$$

Does this make sense?

a. Yes
b. No
c. OK – but needs some refinement

Collision analysis + ideal gas equation of state

$$P = \frac{N}{3V} mv^2 = \frac{Nk_B T}{V}$$

$$\Rightarrow k_B T = \frac{1}{3} mv^2$$

Note that *v* denotes the magnitude of the translational velocity.