Physics 141.
Lecture 21.

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Physics 141.
Lecture 21.

- Course information.
- Experiment 5: updates.
- Quiz
- Start of our discussion of Chapter 12: Entropy.
  - Reversible and irreversible processes.
  - Statistical models.
  - Entropy.

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Physics 141.
Course information.

- No homework due this week.
- No homework due next week.
- Homework # 10 is due on Friday 12/6 at 12 pm.
- Homework # 11 is optional and is due on Friday 12/13 at 12 pm.

- Part II of lab # 5 (video analysis) will take place on Monday November 25 in B&L 407.
- Office hours for lab # 5 on Monday December 2.
- Lab report # 5 is due on Friday December 6. Requests for extensions will not be honored.

- There will be no office hours and recitations this week.
- There will be no office hours and recitations next week.

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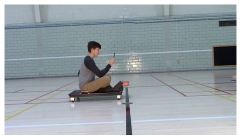
Analysis of experiment # 5. Updated Timeline.

- ✓11/14: collisions in the May room
- ✓ 11/18: analysis files available.
  - https://www.pas.rochester.edu/~tdimino/phy141/lab05/
- 11/25: each student has determined his/her best estimate of the velocities before and after the collisions (analysis during regular lab periods).
- 11/25: complete discussion and comparison of results with colliding partners and submit final results (velocities and errors).
- 11/27: results will be compiled, linear momenta and kinetic energies will be determined, and results will be distributed.
- 12/2: office hours by lab TA/TIs to help with analysis and conclusions.
- 12/6: students submit lab report # 5.



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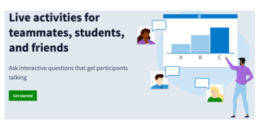
Quiz lecture 21. PollEv.com/frankwolfs050

- The quiz today will have four questions. All answers are correct.
- I will collect your answers electronically using the Poll Everywhere system.
- You have 30 seconds to answer each question.



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Reversible and irreversible processes.

- Many processes in physics are reversible.
- Consider the example of a two-dimensional collisions:
  - You will not be able to tell the difference between the movie being played forward and the movie being played in reverse.
  - In both directions, the collision looks possible.
  - This process is completely reversible.

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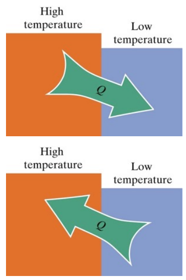
Reversible and irreversible processes.

- Irreversible processes are processes that are highly unlikely to occur in nature.
- In most cases there is no fundamental physics principle that make the reverse process impossible.
- But if the chance that the reverse process happens is essentially 0, the process is called irreversible.



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Reversible and irreversible processes.

- In order to determine whether a process is reversible or irreversible, we must rely on statistical arguments to determine the likelihood that a certain process occurs.
- In Chapter 12 we will use statistical theories to determine the energy distributions among objects, to determine the velocity distributions of gas atoms, etc.
- This area of physics is called **statistical mechanics**.

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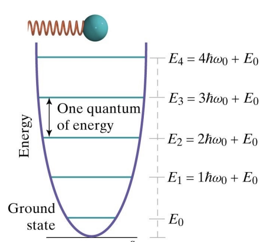
Distributing energy. N = 1.

- Consider an atom, constraint in such a way that it only has one degree of freedom.
- We will also assume that it only can carry out vibrational motion.
- If the atom absorbs 4 quanta of vibrational energy, we know without any doubt it will undergo a transition from its ground state to its fourth excited state, E_4.



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Distributing energy.
N = 2.

- Now consider the situation where the atom has two degrees of freedom; each degree of freedom has a vibrational character with the same characteristic frequency.
- Consider what happens when this system absorbs 4 quanta of vibrational energy.
- We see that there are 2 configurations in which there is a 4:0 energy distribution, 2 configurations in which there is a 3:1 energy distribution, and 1 configuration in which there is a 2:2 energy distribution.

Config.	Degree 1	Degree 2
1	4	0
2	3	1
3	2	2
4	1	3
5	0	4

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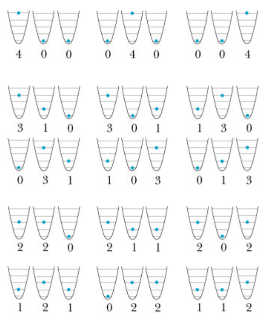
Distributing energy.
N = 3.

- Now consider the situation where the atom has three degrees of freedom; each degree of freedom has a vibrational character with the same characteristic frequency.
- For this system we find:
  - 3 ways: 4:0:0 configuration.
  - 6 ways: 3:1:0 configuration.
  - 3 ways: 2:2:0 configuration.
  - 3 ways: 1:1:2 configuration.
- What is the probability to see the different configurations?



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Distributing energy.
The fundamental assumption.

- In order to determine the probability to observe a certain configuration, we rely on **the fundamental assumption of statistical mechanics** to make this determination:

  A fundamental assumption in statistical mechanics is that in our state of microscopic ignorance, each microstate (microscopic distribution of energy) corresponding to a given macrostate (total energy) is equally probable.

- For example N = 3:
  - 15 microstates; probability of each one is 1/15.
  - 3 ways: 4:0:0 configuration (20% probability).
  - **6 ways: 3:1:0 configuration (40% probability).**
  - 3 ways: 2:2:0 configuration (20% probability).
  - 3 ways: 1:1:2 configuration (20% probability).

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Distributing energy. Two N = 3 atoms.

- Consider now a system with two atoms, each with three degrees of freedom.
- The number of states for n = 1, 2, 3, and 4 quanta in a given atom are easily determined:
  - n = 1: 100, 010, 001
  - n = 2: 200, 110, 101, 020, 011, 002
  - n = 3: 300, 210, 201, 120, 111, 102, 030, 021, 012, 003
  - n = 4: 400, 310, 301, 220, 211, 202, 130, 121, 112, 103, 040, 031, 022, 013, 004
- The most likely microstate is thus the 2:2 state.

Atom 1	Atom 2	# states
n = 4	n = 0	15 x 1
n = 3	n = 1	10 x 3
n = 2	n = 2	6 x 6
n = 1	n = 3	3 x 10
n = 0	n = 4	1 x 15

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3 Minute 46 Second Intermission.

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 46 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWorK problem.

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Distributing energy. Arranging quanta.

- Extending our study to more complex systems (with more degrees of freedom) is not too difficult.
- If we want to distribute q quanta among N one-dimensional oscillators, we find that the number of possible ways is equal to

$$\# = \frac{(q+N-1)!}{q!\,(N-1)!}$$

- Note: $q! = q \times (q-1) \times (q-2) \times (q-3) \times \ldots \times 2 \times 1$.

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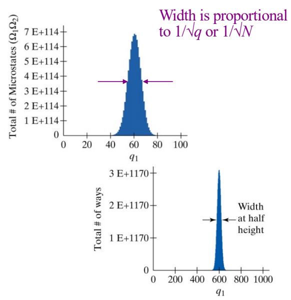
Distributing energy.
Arranging quanta.

- We can verify the previous equations by considering the case where we have up to 4 quanta to be arranged among 3 one-dimensional oscillators.
- Note: 0! = 1.
  - Why?
  - *n*! = *n* x (*n*-1)! If 0! was 0, 1! would be 0, etc. etc.
- The previous equation predicts the correct number of states for this system.

q	N	#
0	3	2!/(0! 2!) = 1
1	3	3!/(1! 2!) = 3
2	3	4!/(2! 2!) = 6
3	3	5!/(3! 2!) = 10
4	3	6!/(4! 2!) = 15

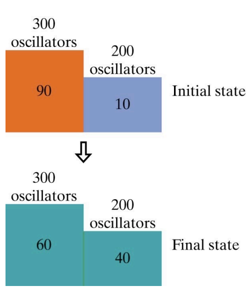
Distributing energy.
Number of microstates.

- The number of possible microstates quickly becomes very larger when we increase the number of oscillators.
- Consider two blocks, brought in contact. One block has 300 oscillators (100 atoms) and the second block has 200 oscillators (67 atoms).
- When we distribute 100 quanta of vibrational energy among the blocks, we find that the maximum number of states occurs when 60 quanta are given to the first block and 40 to the second block.



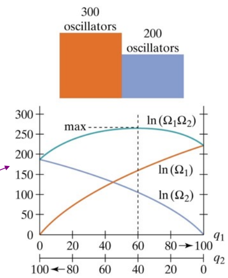
Distributing energy.
Achieving equilibrium.

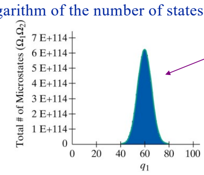
- Consider bringing the two blocks in contact when the first block has 90 quanta of vibrational energy and the second block only 10.
- The process of exchange of energy is a random (statistical) process, the direction of transfer will be in the direction in which the number of possible states increases.
- The exchange of energy will continue even when the most probable distribution is reached, but at that point there will only be small fluctuation around the most probable distribution.



Distributing energy. Number of states: different representations.

- Since the number of states of a system is enormous (even for small system with a few hundred oscillators) it is often more convenient to look at the natural logarithm of the number of states.





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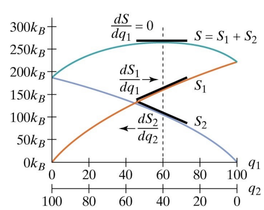
Entropy.

- Since the evolution of the system depends on the number of microstates, the concept of entropy is introduced.
- The entropy S of one of the blocks we have been discussing is defined as

$$S = k \ln(\Omega)$$

where k is the Boltzmann constant (1.4×10^{-24} J/K).
- The entropy of the total system is the sum of the entropy of the blocks that make up the system.



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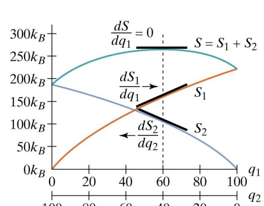
Entropy.

- The most probable configuration of the system of the two blocks is the configuration for which the entropy has a maximum.
- When we bring two blocks of different temperature in contact, energy exchange will take place until the system has achieved thermal equilibrium.
- Thermal equilibrium is defined as the energy distribution which maximizes the entropy of the system (in this case the two blocks).



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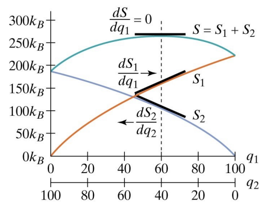
Entropy and the Second Law of Thermodynamics.

- To achieve thermal equilibrium, the system will maximize its entropy.
- The most likely evolution of the system is the focus of the **second law of thermodynamics**:
  If a closed system is not in equilibrium, the most probable consequence is that the entropy of the system will increase.
- Note: even when the two blocks are in thermal equilibrium, there may still be exchange of energy between the blocks, but the time averaged energy exchange will be zero.



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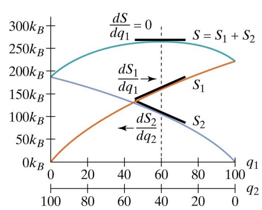
Entropy and the Second Law of Thermodynamics.

- If we know the entropy as function of for example the number of vibrational quanta of block 1, we can express the condition for equilibrium as

$$\frac{dS}{dq_1} = \frac{dS_1}{dq_1} + \frac{dS_2}{dq_1} = 0$$

or

$$\frac{dS_1}{dq_1} = -\frac{dS_2}{dq_1}$$



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Enough physics for today!

KLM 641

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