Physics 141.
Lecture 21.

Carry-on Luggage.

Physics 141.
Lecture 21.

- Course information.
- Experiment 5: analysis details.
- Concept test.
- Start of our discussion of Chapter 12: Entropy.
  - Reversible and irreversible processes.
  - Statistical models.

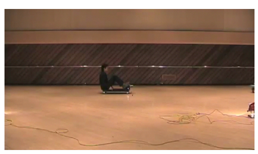
Physics 141.
Course information.

- Homework # 9 is due on Friday 11/18 at 12 pm.
- Homework # 10 is due on Friday 12/2 at 12 pm.
- Data analysis of lab # 5 will take place on Monday 11/21.
- I will not have office hours on today. Instead I offered virtual office hours on Wednesday night.

Physics 141.
Lab # 5. Now what?

Analysis lab # 5: know the goals before you start your video analysis!

- The analysis of lab # 5 will involve the following steps:
  - The videos will be analyzed using LoggerPro.
  - Each student will analyze the two or three collisions in which they were involved and determine the two velocities before and after each collision.
  - The students involved in each collision compare the velocities they determined and use them to either catch "silly" mistakes or obtain their best estimates of their velocities and the errors in their estimates.
  - All velocities are converted to momenta and kinetic energies, and the entire data sets forms the basis of lab report # 5.



Physics 141.
Lab # 5.

- The analysis of this experiment is complex:
  - Information about the collisions will available on the web (names, can deformations, etc.).
  - The two colliding students who look at the same collision need to compare their values for the velocities before and after the collision in order to determine the errors in their values (and catch any mistakes in the analysis of the video clips).
  - For each collision I expect you to submit a web form with all velocities and their errors for that collision.
  - I will convert the measured velocities to momenta and kinetic energies and publish the data on the web.
  - Each student will look at the entire data set and compare losses in kinetic energy with the deformation of the cans.
  - The lab report covering this experiment will receive the same weight as lab report # 4. You should know now what makes a lab report great!
  - Let's look at the various steps in a bit more detail.

Lab # 5. Finding the collision time.

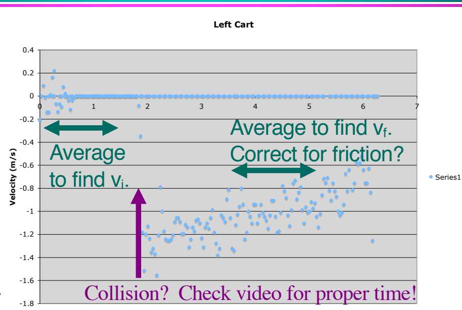
- The first step in interpreting the results of the video analysis is to determine the collision time.
- This can be done in LoggerPro or by looking at the results of the video analysis in Excel.
- Besides determining the collision time, it is also important to determine what time interval after the collision you should use to determine the final velocities (e.g. motion of the body will influence motion of the cart).

Calibration: wheel-to-wheel length of cart = 0.766 m.

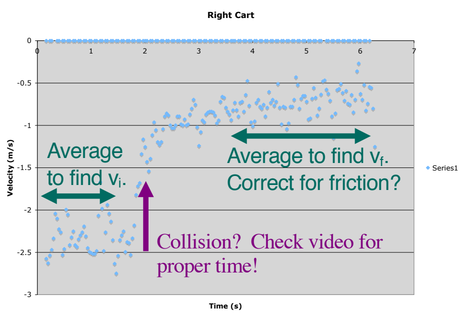
Lab # 5. Position versus Time.

Lab # 5. Finding velocities. Left Cart.

The initial velocity should be 0 m/s! What do you get? Provides info about the accuracy of the procedure.



Lab # 5.
Finding velocities. Right Cart.



Lab # 5.
How to determine the velocities?

- Any time you have a large number of data, use tools to process them quickly (e.g. there is no learning involved in using your calculator to find the average of 100 numbers).
- **For professional graphs and curve fitting you should use Igor. This also will make it MUCH easier to determine the errors in the velocities!**

Lab # 5.
Combining two analyses.

- The results of two independent analyses need to be combined.
- The two results can also be used to catch mistakes in one of the analyses.
- Example 1:
  - $v_{left,f,1} = -5.2 \pm 0.4$ m/s
  - $v_{left,f,2} = -0.2 \pm 0.1$ m/s

  Calibration problems or reversal of cars?
- Example 2:
  - $v_{left,f,1} = -3.2 \pm 0.4$ m/s
  - $v_{left,f,2} = -2.2 \pm 0.4$ m/s

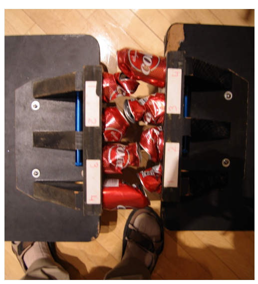
  These two results look consistent and can be combined to obtain the following estimate for the final velocity of the left cart:
  - $v_{left,f} = -2.7 \pm 0.3$ m/s

Lab # 5.
What do we learn?

- Based on the velocities determined, I will calculate the initial and final momenta and kinetic energies.
- The can deformations will be available on the WEB.
- We expect that the deformation of the cans is related to the loss of kinetic energy (since it takes energy to deform the cans).
- Models to consider:
  - Loss of kinetic energy is proportional to the deformation of the cans.
  - Loss of kinetic energy is proportional to the square of the deformation of the cans.
- Is linear momentum conserved?

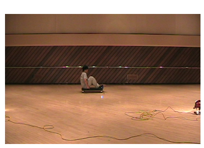
Analysis of experiment # 5.
Models to be considered.

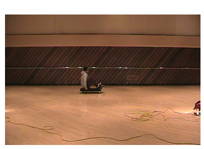
- Consider the following models:
  - Can force = F = const. Work done = $-\Sigma(Fx_i) = \Delta K$.
  - Can force = kx. Work done = $-\Sigma(\frac{1}{2}kx_i^2) = \Delta K$.
  - A combination of these two forces:
    - Force = F if $x_i < x_0$
    - Force = kx if $x_i > x_0$



Analysis of experiment # 5.
Timeline (more details during next lectures).

- ✔11/14: collisions in the May room
- 11/20: analysis files available.
- 11/21: each student has determined his/her best estimate of the velocities before and after the collisions (analysis during regular lab periods).
- 11/23: complete discussion and comparison of results with colliding partners and submit final results (velocities and errors) to professor Wolfs.
- 11/25: professor Wolfs compiles results, determines momenta and kinetic energies, and distributes the results.
- 11/28: office hours by lab TA/TIs to help with analysis and conclusions.
- 12/2: students submit lab report # 5.

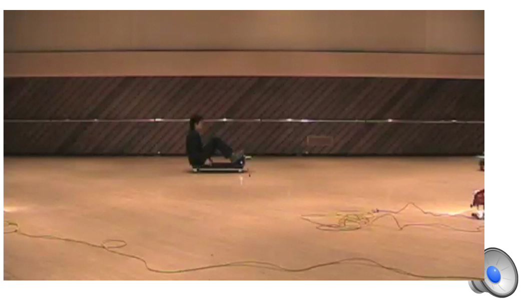




Physics 141: Concept Test. Did you really fully understand angular momentum?

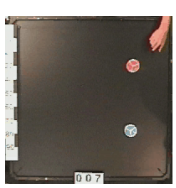
- Let us practice what we have learned so far.
- This test allows me to assess your understanding of the material, but will not be effect your Physics 141 grade.
- Your PRS will be used to enter your answers.

5 Minute 39 Second Intermission.



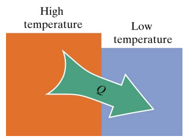
Reversible and irreversible processes.

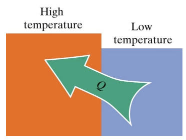
- Many processes in physics are reversible.
- Consider the example of a two-dimensional collisions:
  - You will not be able to tell the difference between the movie being played forward and the movie being played in reverse.
  - In both directions, the collision looks possible.
  - This process is completely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



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.



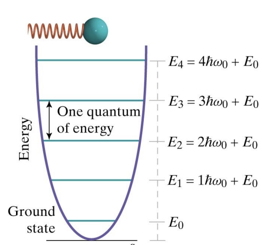


Reversible and irreversible processes.

- 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**.

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.



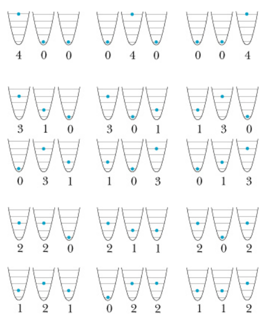
Distributing energy.
N = 2.

- 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

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?



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 = 2: 5 microstates; probability of each one is 1/5.
  - N = 3: 15 microstates; probability of each one is 1/15.

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

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 amount N one-dimensional oscillators we find that the number of possible ways is equal to

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

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

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

Enough physics for today!

KLM 641