NOTE: Today's activities must be done in teams of **one** or **two**. There are now twice as many computers in the room, and twice as many lab notebooks. Please split up into pairs or find a computer and notebook to work alone; *no teams of 3 or 4 today!* As usual, don't forget to write your name or names on the first blank page of your notebook before you start. Also put the date and number your pages.

Today's Textbook Reference to review before Practical:
"Principles & Practice of Physics" 1st Edition by Eric Mazur ©2015
Chapter 10 from "Principles", particularly Section 10.7. Example 10.6 in particular is vital to understand.
Supplemental Reading from Wikipedia:
Drag Equation:
http://en.wikipedia.org/wiki/Drag_equation

In this exercise we will investigate projectile motion, with and without air resistance.

- There are questions asked of you throughout this assignment, labeled **Question 1**, **Question 2**, etc. Write down the answers in the lab notebook (to be handed in at the end of the Practical).
- At the end of the Practical, hand in your lab notebook, along with a printed copy of your code for the final exercise
- If you are working with a partner, the two of you must reach a consensus about an answer before moving on to the next part. Feel free to ask the TA for help if a consensus cannot be reached.
- All quantities are in SI units; distance in meters (m), time in seconds (s), velocity in m/s, acceleration in m/s^2, and mass in kg.

Exercise A: Projectile Motion in a Vacuum

Question 1
A ball is launched with an initial speed v_0, and an initial launch angle θ_0. The acceleration due to gravity is $g = 9.80$ m/s^2, downward. How far, horizontally, from the launch position will the ball be when it returns back to the same initial height? (This distance is called the *horizontal range* of the projectile.) [Neglect air resistance.]

Question 2
If you wish to hit a "home run" in baseball, your horizontal range must be at least 100 m. What is the minimum initial speed you need to hit a home run, and what is the best initial launch angle? [Neglect air resistance.]

On the Practicals section of the course website under week 9 is the program "lab9exA.py". Download this program and save it on your computer.

Question 3
Read the code carefully. There is a "bug" somewhere in this code. There is only one major bug on one line that is making the code crash with a syntax error. Debug the code so that it no longer crashes. Write in your notebook what the old and new line were that you fixed.

Now that the code is running, give it a few tries. You have to input an initial speed, and it computes the maximum range and best range angle. If the range is longer than 100 m, it tells you that you got a "home run". The code also outputs a comma-separated-value file "projectileA.csv" which you can read into excel and make a chart of the best trajectory.

Question 4
Run the program with the speed you computed in question 2. Did you get a home run? Try modifying the angle-step size and the time-step for numerical integration. Note this numerical integration is rather crude, so you won't get exact results. You might have to adjust the initial speed a bit upward. Don't reduce the angle-step size and time-step too much or the code will take too long to run! Once you have a range you like, open up the output file with Excel, highlight the first two columns and insert a scatter plot. Print this graph and staple it into your notebook along with the relevant parameters of the numerical integration.

Exercise B: Projectile Motion of a Baseball in Air

When a real baseball flies through the air, there is air resistance. Air resistance is studied in fluid dynamics and its origins are complex, but for most normal speeds and ordinary-sized objects here on earth that are not rotating, air resistance can be modeled by the drag equation:
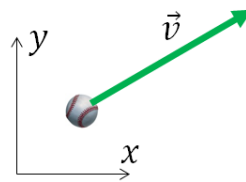
$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Here F_D is the magnitude of the drag force in Newtons. The direction of $\vec{F}_D$ is opposite the direction of the ball's velocity relative to the air, $\vec{v}$, which is in m/s in this equation. ρ is the density of the air, $\rho = 1.2$ kg/m^3. A is the cross-sectional area of the ball in m^2. C_D is the drag coefficient - a dimensionless coefficient related to the object's geometry and taking into account both skin friction and form drag (http://en.wikipedia.org/wiki/Drag_equation). Note that for a baseball going between 20 and 50 m/s, the drag coefficient is approximately $C_D = 0.5$.

So as the ball flies through the air, there are two forces acting: the drag force and gravity. The net force on the ball is the vector sum: $\vec{F}_{net} = \vec{F}_D + \vec{F}_G$.
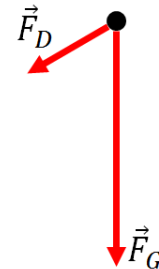
Question 5

What are the *x*- and *y*-components of the net force on the ball as it travels through the air? Write equations for the force F_x and F_y components in terms of the following variables *only*:

Free-body diagram for ball:

- the instantaneous velocity components v_x and v_y
- the mass of the ball *m*
- the radius of the ball *r*
- the density of air ρ
- the drag coefficient of the ball C_D

Save a new copy of the .py file you used in Exercise A, call it "lab9exB.py". Edit the code to include air resistance.

Question 6

If you wish to hit a "home run" in baseball, your horizontal range must be at least 100 m. What is the minimum initial speed you need to hit a home run, and what is the best initial launch angle? [Include air resistance!] Make sure your result doesn't depend much on the angle-step size and the time-step for numerical integration. Once you have a trajectory you like, open up the output file with Excel, highlight the first two columns and insert a scatter plot. Print this graph and staple it into your notebook along with the relevant parameters of the numerical integration. Print your code and staple it into your notebook as well.

Some quirks about Python code which might be good to know:

- To raise something to a power, use `**`, not `^`. (Ie, x^2 is `x**2`)
- When you use integers in an operation, python forces the answer to be an integer. For example, `(1/2)` is truncated to 0! You have to use `(1.0/2.0)`, which will give 0.5.
- Python will not overwrite a file that is currently open in another program. So if you are viewing the output .csv file with Excel, you have to close Excel before you can re-run the python code.

Bonus Question If You Have Time

What if the baseball had all the same properties except its mass was half as much? What would be the required initial speed and best launch angle for a home run? Plot this trajectory.

[Note: This Module was written by November 2014. Last modification by Jason Harlow on Nov. 17, 2014.]