1. (3 pts) **Galileo’s Analysis of Projectile Motion**
   The above picture represents the flight of a ball thrown into the air (although air resistance effects have been neglected). The background grid is in 20 cm. squares. The blobs represent the position of the ball at successive 0.2-second intervals.

   (a) By counting lines, find the average horizontal velocity of the ball, in meters per second, during the first fifth of a second. (Remember, each square is 20 cm. across (from side to side or top to bottom), and average speed = distance/time.)

   Between red dots are 8 horizontal steps, so 160cm. Since the time/step is 0.2s, the horizontal speed is 160cm/0.2s = 800 cm/s.

   (b) By reviewing the whole picture, find how the horizontal velocity (in meters per second) varies throughout the flight.

   The horizontal spacing is the same between each adjacent pair of dots, so horizontal velocity is constant (unaccelerated).

   (c) By counting squares, find the average vertical velocity of the ball during the first fifth of a second.
During 1st 0.2 s, ball rises 7 squares or 140cm. Average vertical velocity is therefore 140cm/0.2s = 700cm/s.

(d) Make a table of the ball's average vertical velocity for all eight 0.2-second periods in the flight. Count velocity upwards as positive, downwards as negative.

<table>
<thead>
<tr>
<th>Interval</th>
<th>(v_y) (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.2s</td>
<td>700</td>
</tr>
<tr>
<td>0.2-0.4s</td>
<td>500</td>
</tr>
<tr>
<td>0.4-0.6s</td>
<td>300</td>
</tr>
<tr>
<td>0.6-0.8s</td>
<td>100</td>
</tr>
<tr>
<td>0.8-1.0s</td>
<td>-100</td>
</tr>
<tr>
<td>1.0-1.2s</td>
<td>-300</td>
</tr>
<tr>
<td>1.2-1.4s</td>
<td>-500</td>
</tr>
<tr>
<td>1.4-1.6s</td>
<td>-700</td>
</tr>
</tbody>
</table>

(e) Use your results from part (d) to plot a graph of the ball's vertical velocity (on the y-axis) as a function of time (on the x-axis) for the whole flight.

(f) What can you conclude about the acceleration (instantaneous change of velocity) of the ball at the topmost point of the path?

Since \(v\) vs. \(t\) is a straight line, each average acceleration (slope) in each interval is the same, and the acceleration is always negative and equal to about \(\Delta v/\Delta t = (200 \text{ cm/s})/0.2s = 1000\text{cm/s}^2 = 10 \text{ m/s}^2\) down.

(g) Suppose now instead that the ball had been thrown directly upwards. Would it be accelerating at the topmost point of its flight?

Yes, same acceleration due to gravity, 10 m/s\(^2\) down.
(h) Galileo states in *Two New Sciences* "so far as I know, no one has yet pointed out that the distances traversed, during equal intervals of time, by a body falling from rest, stand to one another in the same ratio as the odd numbers beginning with unity". (The odd numbers beginning with unity just means 1, 3, 5, 7, ...). Show how you can verify this assertion using the picture above. What are the total distances (Δy) fallen at the end of each fifth of a second starting from the topmost point?

Count # squares (down, after topmost point): 1,3,5,7… *Total # squares are 1,4,9,16…* To get the total change in y, just multiply by the size of each square. So total change in y is 20,80,180,320,…

2. **Newton's cannon.** When Newton’s cannon is shooting at a low speed, it’s clear that the cannonball follows the usual path, accelerating towards the ground. Explain in your own words how it can be that, at the right fast speed, shot above the atmosphere, the cannonball will stay at the same height, and never reach the ground. Make clear whether or not it is accelerating, and in what direction. (It might help to look at the applet [http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/NewtMtn/NewtMtn.html](http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/NewtMtn/NewtMtn.html)).

If the cannonball has the right initial speed, the distance it falls towards the earth in a given time will be compensated by the Earth’s surface curving out from underneath it, and it will therefore not approach any closer to the surface!

3. In your reading from Newton's *General Scholium*, he makes what became his famous statement about not making hypotheses. What specific scientific question was he refusing to make hypotheses about?

The cause(s) of gravity.

4. At one point Newton thought he was going to be forced to leave Cambridge University. Why? (See Gregory, Chapter 8)

To stay at Cambridge required that Newton be ordained into the Anglican clergy, but his belief that Jesus was not co-equal with God the father was incompatible with ordination.

5. Describe the debate between Newton and Robert Hooke about the *causes* of circular planetary motion. What were their initial positions on the question? What was Newton’s ultimate conclusion? (Gregory, Ch. 8)

Initially Newton, who had thought about the moon’s motion since he was a student, felt that circular motion must be a combination of two balancing forces, one tending to make the moon fall, and one pushing it outward. Hooke wrote Newton in 1679, arguing that the moon’s tangential motion, plus an attractive force pulling the moon inward, was sufficient to explain the circular trajectory. Newton ultimately realized that Hooke was correct, a difficult conclusion because Hooke had criticized his work in the past and had been his strongest competitor.