# 1 Video Problems

## 1.1 What are they?

A video problem is a subset of the category "application experiment". From each video one can determine a physical quantity such as the coefficient of friction between two surfaces, the height of a table, etc... by two independent methods. The results determined from each method should agree with each other.

## 1.2 Why do you want to use them?

- Promoting epistemic cognition:
  Video problems are ill-defined complex problems. Students have to make experimental decisions about data collection; they need to make theoretical decisions related to the simplifications of objects and processes, and they need to use their judgment whether the result is reasonable.

- Promoting scientific abilities:
  Solving a video problem requires students to employ scientific abilities such as the ability to collect and analyze data, the ability to build a model of a situation, and so on.

- Promoting concrete experiences:
  Video problems move the traditional "back of chapter" problem into a meaningful real world context.

- Promoting descision-making:
  In contrast with traditional back-of-chapter problems, students make scientific decisions such as "should I neglect friction?" rather than *telling* students that they should neglect friction. Requiring students to make such decisions is more in line with the activities of scientists in the real world and is a cornerstone of our method.

- Distinguishing between theoretical assumptions and experimental uncertainties:
  While solving an experimental problem students need to decide whether they can neglect air resistance, surface resistance, masses of pulleys, etc. They also need to evaluate how precise the measurements are.

- Helping students see the coherence of physics:
  As students are required to use two methods to determine the same quantity, they see the coherence of physics knowledge.

- Alleviating cognitive load:
  A video problem can be used to present relatively "clean" real world data and affords the opportunity to collect data in novel ways such as stepping frame by frame. This

alleviates some of the cognitive load on students from having to sift through "messy" data.

### 1.3 How do you use them?

Students can work individually or in groups of two. After they read the problem and learn what quantity to determine, they watch the video and decide what quantities can be measured, and how the desired quantity can be calculated using the information gleaned from the video. The information about how a clip was digitized is provided for students (for example: 15 fps or 30 fps). Some videos contain a ruler as a length measuring instrument. Then students watch the clip again, frame by frame, collect the data, analyze them and use them to determine the unknown quantity. Then they compare the results of the two methods and decide what contributed to the difference between them: theoretical assumptions or experimental uncertainties.

Students should attempt video problems after they have constructed a relationship/ explanation of a related phenomenon and feel comfortable applying it. We envision video problems being used in the following contexts:

- As a formative assessment assignment in recitation or in class (with a rubric for self assessment),
- as a laboratory experiment (with a rubric for self assessment),
- as a homework problem (with a rubric for self assessment),
- as an exam question.

### 1.4 What are some types?

Video problems can cover almost any area of physics. The main consideration is that you can present students with two independent methods of estimating a physical quantity. The only limitation is your imagination! For example: A video of a ball being thrown straight up. Students can estimate the height of the throw by either using some familiar object in the video as a reference length, they can measure the time of flight of the ball from release to the top of its trajectory and apply their model of motion with a constant acceleration to find the distance travelled, or they can estimate the initial speed from the distance traveled in one frame and then find the height.

### 1.5 How do you score them?

A sample of the throw problem mentioned previously is presented with a model solution and a sample of student work. After this we present a rubric and a sample scoring with reasons as to why particular scores were given.

## Model Solution

In both methods the height to which the ball is thrown will be measured from the sill of the chalkboard. Some reasonable fixed point needs to be specified by the student.

**Method 1**

From the video it is given that the ruler is 1.5m long which corresponds to 4.7cm on MY computer screen. The ball rises a further 3.3cm above the top of the ruler. Thus we can get an expression for the total height relative to the sill:

$$\text{Total height} = 1.5\text{m} + 3.3\text{cm} \times \frac{1.5\text{m}}{4.7\text{cm}} = 2.55\text{m}$$

It is unclear how much uncertainty there is in this measurement. The dominant source of error is NOT the resolution limit of the ruler. The dominant problem is a problem of parallax due to the change in perspective. It is impossible to estimate the effect of this because it is difficult to see how close the ball is to the wall. One should predict however that because of the parallax this measurement should *overestimate* the height. Students who use the parallax argument to explain why this estimate is less than the method 2 estimate should be marked down in the rubric.

**Method 2**

We use the time of flight to estimate the height above some selected point. This point should be selected to satisfy the following 2 criteria: (1) The ball must have left the hand so that a constant acceleration model is applicable, (2) The ball is roughly parallel to the height of the camera so that parallax does not ruin the measurement.

Here I picked the frame where the ball is at the 130cm mark on the ruler. From this point, it is 15 frames to the top of the trajectory with an uncertainty of about half a frame (This comes from experience of filming - an estimate of 1 frame is acceptable). Converting time of flight into seconds, we use the fact that the film plays at 30fps, thus t=15frames/30fps=0.5s. Students need to indicate that they will apply a model of constant acceleration, ignoring the effects of friction on the motion of the ball. This is acceptable because the time of flight is relatively short. Taking up as positive, students need to show that the height $y = \frac{1}{2}gt^2$. This may be shown from $v = u - gt$. Since $v = 0$ at the top of the flight, $u = gt$. Plugging this result into $y = ut - \frac{1}{2}gt^2$ we get $y = \frac{1}{2}gt^2$. Thus:

$$\text{Total height} = 1.3\text{m} + \left(\frac{1}{2}\right)(9.8\text{m/s}^2)\left(\frac{1}{2}\text{s}\right)^2 = 2.53\text{m}.$$

Estimating an upper bound for the error can be done by considering an uncertainty of about half a frame in estimating the time of flight. Thus $\Delta t = 1/60$s. Using basic calculus we can estimate that $\Delta y = 2\times\frac{1}{2}gt\Delta t$. This gives $\Delta y \approx 8$cm. This is arguably the dominant source of uncertainty in this measurement

Finally students should compare their two answers. Something like this: My two answers agree to within the limits of experimental uncertainty. I attribute the slightly higher answer in method 1 to parallax and conclude that a model of constant acceleration is definitely applicable to estimate the height of the ball in this situation.

# Example of Student Work

Home

Existing users log in here or new users sign up here.

Kinematics Puzzles

Mechanics Puzzles

Mechanics Anomalous Data

Fluids Anomalous Data

Optics Anomalous Data

## How high was the ball thrown?: Application Experiment

### Aim

Estimate how high the ball is thrown using two independent methods

### Prior Knowledge

1. Kinematics

### Description of the Experiment

A ball is thrown straight up. Use the video to figure out how high the ball is thrown via two independent methods. Remember to specify your estimate relative to some fixed point. Write down the procedures you are going to use.

### Addtional Information

For one method there is a ruler in the picture to help you make and estimate. The ruler is 1.5m long and has a number printed every 20cm.

**Frame rate:**
30fps

**Size:**
320 X 480

**File Size:**
0.50Mb

QuickTime

### Questions

Do your two estimates of the height agree? If not, why not? Which estimate do you think is more reliable?

HOW HIGH WAS THE BALL THROWN?

BEGIN: 10:00AM

GOAL: USE TWO INDEPENDENT METHODS TO ESTIMATE HOW HIGH THE BALL IS THROWN.

METHOD 1: USE RULER

DATA

GIVEN:
- RULER IS 1.5m LONG
- RULER HAS NUMBER PRINTED EVERY 20 cm.

OBSERVED DISTANCES

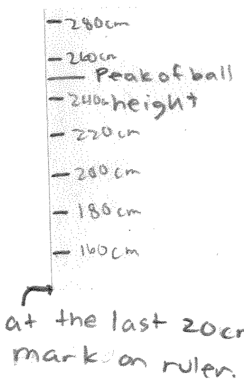
HEIGHT AT WHICH BALL WAS RELEASED: 60 cm point

PEAK HEIGHT OF BALL: APPROX* - 250 cm point

HEIGHT BALL THROWN: 190 cm

UNCERTAINTIES

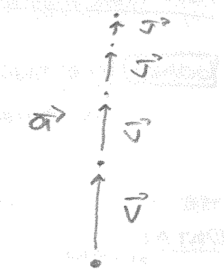
- It was difficult to estimate both the height at which the ball was released and the peak height the ball.




- To approximate the ball's release point. I watched the video frame by frame. At the point where the hand lost contact with the ball is the releasepoint I marked down.
- To approximate the peak height of the ball, I again watched the video frame by frame, At the highest point is where I marked the down the peak. Since this point was beyond the ruler length, I used a post-it to mark the 20cm intervals to extend the ruler range.

- The sources of uncertainty is mainly due to eye judgement approximations. In marking the point of release, the frame is blurry so it was difficult to mark exactly where the ball was released. (Give or take 10-20cm) In marking the peak height, the post-it approximations was very crude. I mearly traced the intervals on the ruler and then used the tracing to extend the ruler range.

METHOD 2:



DATA

GIVEN:

- FRAME RATE is 30 frames per second
- $\text{height} = V_0 t + \frac{1}{2} a t^2$
- $V_f = V_0 + at$
- $a = -9.81\,m/s^2$

OBSERVATION

- From release point to peak height was 19 frames

CALCULATIONS

- $19\text{ frames} \times \frac{1}{30}\text{ sec.} = \frac{19}{30}\text{ seconds} = 0.633\text{ sec.}$
- $V_f = 0$
  $a = -9.81\,m/s^2$
  $t = 0.633\,s$
  $V_0 = ?$

  $V_0 = V_f - at$
  $V_0 = 0 - (-9.81\,\frac{m}{s^2})(0.633\,s)$
  $V_0 = 6.21\,m/s$
- height = ?
  $V_0 = 6.21\,m/s$
  $t = .633\text{ sec}$
  $a = -9.81\,m/s^2$

  $\text{height} = V_0 t + \frac{1}{2} a t^2$
  $\text{height} = (6.21)(.633) + \frac{1}{2}(-9.81)(.633)^2$
  $\text{height} = 3.93 - 1.97$
  **height = 1.97 m**

UNCERTAINTIES

- There was uncertainty due to the frame by frame observation. The image was blurry so it was difficult to approximate the point of release. (Give or take a frame) If 20 frames then height should be 2.18 m. If 18 frames, then the height should be 1.76 m.

ASSUMPTIONS MADE

- $a = -9.8\,m/s^2$; the ball decelerates constantly at $-9.81\,m/s^2$ as it moves upward
- Assume wind resistance is negligible.

EVALUATION

The height from both methods were very close to each other (190 cm, 197 cm). These results, though precise may still not be accurate. Both methods relied on eye judgement and so the data was limited to this uncertainty. I may just systematically have bad eye judement. To find out if these results are accurate, (1) I could repeat the experiment with better measuring, (2) others could do the experiment and then compare our results. To find out if I have systematically bad eye judement, I could perform another experiment requiring eye judgement and see if I consistently get lower or higher than the actual.

If indeed I am accurate and precise, I can say that the equations I used SHOULD be used in kinematics calculations for similar scenarios.

END: 11:15 AM

6/23/04

# Example of rubric scoring

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to identify sources of experimental uncertainty | No attempt is made to identify experimental uncertainties. | An attempt is made to identify experimental uncertainties, but most are missing, described vaguely, or incorrect. | Most experimental uncertainties are correctly identified. | All experimental uncertainties are correctly identified. |

**SCORE: 3**

All the really important sources of uncertainty have been identified.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to evaluate specifically how experimental uncertainties may affect the data | No attempt is made to evaluate experimental uncertainties. | An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect. | Most experimental uncertainties are evaluated correctly, though a few contain minor errors, inconsistencies, or omissions. | All experimental uncertainties are correctly evaluated. |

**SCORE: 3**

The estimates of the amount of uncertainty are all reasonable and there is an explicit worked example of how much a 1 frame uncertainty affects the calculation of the height.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to minimize experimental uncertainties. | No evidence of any effort to make precise measurements from video | Some evidence of an attempt to take precise measurements. Most major sources or uncertainty are ignored or poorly addressed | Evidence of effective data taking such as multiple measurements etc. One major omission or some small oversights | Precise data collection in all aspects afforded by the video. Attention to reducing all obvious sources of random and systematic uncertainty in data collection. |

**SCORE: 3**

A clear reference point is specified and a piece of paper was matched against the ruler on the screen to get the best height estimate possible. (See the post-it note attached to the lower left part of the first page of the student's work.)

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to record and represent data in a meaningful way | Data is either absent or incomprehensible. | Some important data is absent or incomprehensible. | All important data is present, but is recorded in a way that requires some effort to comprehend. | All important data is present, organized, and recorded clearly. |

**SCORE: 3**

All the data is present, easy to find and read, and written with correct units.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to analyze data appropriately | No attempt is made to analyze the data. | An attempt is made to analyze the data, but it is either seriously flawed or inappropriate. | The analysis is appropriate but it contains minor errors or omissions. | The analysis is appropriate, complete, and correct. |

**SCORE: 3**

The analysis is all correct.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to choose a productive and appropriate model AND mathematical procedure for solving each problem (SCORE TWICE, ONCE FOR EACH METHOD) | Model and mathematical procedure is either missing, or wholly inappropriate. | A model and mathematical procedure are described, but are incomplete, due to which the final answer cannot be calculated. | Correct and complete model and mathematical procedure are described but an error is made in the numerical calculations. | Model and mathematical procedure are fully consistent with the data presented in the video. All quantities are calculated correctly. Final answer is meaningful. |

**Method 1: SCORE: 3** **Method 2: SCORE: 3**

Both procedures are correct and appropriate to the given situation.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to identify the assumptions (model assumptions + additional assumptions as needed) made in using the chosen model (SCORE TWICE, ONCE FOR EACH METHOD) | No attempt is made to identify any assumptions. | An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect. | Most assumptions are correctly identified. | All assumptions are correctly identified. |

**Method 1: SCORE: 0** **Method 2: SCORE: 3**

No assumptions concerning method 1 are mentioned. (For example: the student ignored errors of parallax — the assumption is that the ball is sufficiently close to the board and the camera is sufficiently far way that there are negligible distortions.) For method 2, the basic assumptions of the method are that the force of the earth is constant and air friction is ignored. These are both mentioned.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to determine specifically the way in which assumptions might affect the results (SCORE TWICE, ONCE FOR EACH METHOD) | No attempt is made to determine the effects of assumptions. | An attempt is made to determine the effects of some assumptions, but most are missing, described vaguely, or incorrect. | The effects of most assumptions are determined correctly, though a few contain minor errors, inconsistencies, or omissions. | The effects of all assumptions are correctly determined. |

**Method 1: SCORE: 0** **Method 2: SCORE: 0**

No attempt made for either method.

| Scientific Ability | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| Is able to make a judgment about the results of each method and compare and evaluate the results | No discussion is presented about the results of the two methods | A judgment is made about the results, but it is not reasonable or coherent. Little nor no discussion about the differences/similarities of the two results | An acceptable judgment is made about the results, but the reasoning is flawed or incomplete. Discussion about the differences/similarities of the two results with inadequate reasoning. | An acceptable judgment is made about the result. The effects of assumptions and experimental uncertainties are considered in comparing one result to the other. |

**SCORE: 2**

The uncertainty estimates are not mentioned in arguing that the two results are essentially the "same".