SLE123 Physics for the Life Sciences

Week 2

Problem solving

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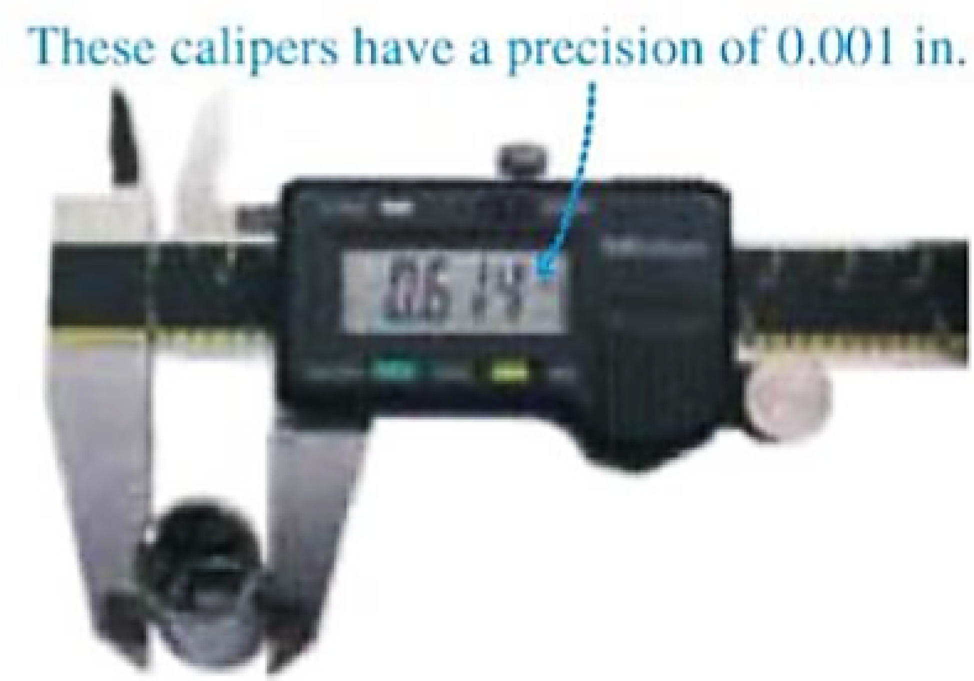
Measurement and Errors

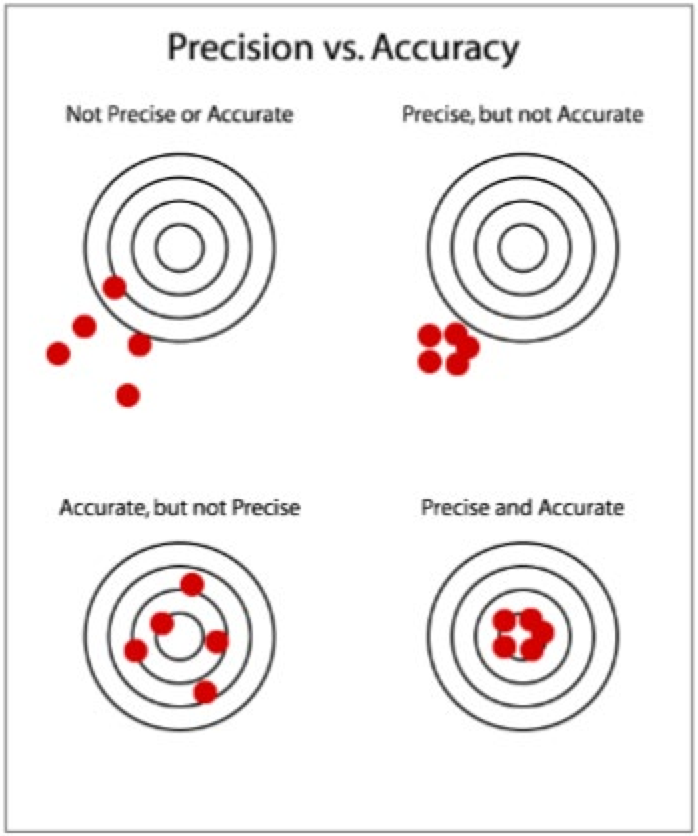
- When we measure any quantity, such as the length of a bone or the weight of a specimen, we can do so only with a certain precision.
- The digital callipers can make a measurement to within ± 0.001 in, so they have a precision of 0.00 1 in.
- If you used the tape shown to make a measurement, you probably couldn't do better than about ± 1 mm, so the precision of the tape measure is about 1 mm.



The precision of a measurement can also be affected by the skill or judgment of the person performing the measurement.
A stopwatch might have a precision of 0.00 1 s, but, due to your reaction time, your measurement of the time of a sprinter would be much less precise.

Precision versus Accuracy

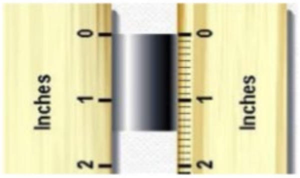
- *Accuracy is a* measure of the agreement of a particular measurement with the “true” (or “accepted”) value
- *Precision measures how closely two or more measurements agree with each other. Precision* is sometimes referred to as ‘repeatability’ or ‘reproducibility’. A measurement which is highly reproducible tends to give values which are very close to each other.

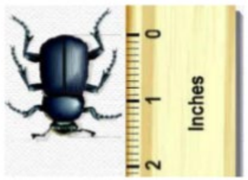


Measurement and Uncertainty

- A simple approach for estimating the uncertainty in a measurement is to report the limiting precision of the measurement tool
- For example, if a balance is calibrated to report masses to 0.1g, then the actual mass of a sample could be up to 0.05g greater or less than the measured mass, the balance would still read out the same value
- Thus, the uncertainty associated with mass measurements using this balance would be ±0.5g

- Note: a useful rule for finding uncertainty associated with a measurement tool is to determine the smallest increment the device can measure and divide that value by 2
- The uncertainty associated with a particular measuring device can be improved b taking multiple measurements and using STATISTICAL ANALYSIS to find the uncertainty





The temperature on the thermometer should be recorded as 30.0 °C not 30 °C

One-Dimensional Motion with Constant Acceleration

- The kinematic equations are a set of four equations that can determine unknown information about an object's motion if other information is known.
- The equations can be used for any motion that can be described as being either a *constant velocity* motion (an acceleration of 0 m/s/s) or a *constant acceleration* motion (both in magnitude and direction).
- They can never be used over any time period during which the acceleration is changing.

Firstly, we have the definition of acceleration.

Since acceleration a is constant, the change in velocity over a given time interval Δt is the acceleration multiplied by the elapsed time:

(a must be constant the entire time interval)

Equation 1

$$a = \frac{v_f - v_i}{\Delta t}$$

One-Dimensional Motion with Constant Acceleration

This next equation is a special case known as the Mean Speed Theorem. It is useful to know but more than that, it helps us get to the next kinematic equation.

If a uniformly accelerated object (starting from rest, i.e., zero initial velocity) travels the same distance as an object with uniform speed whose speed is half the final velocity of the accelerated body.

Equation 2

$$\Delta x = (\text{average } v) \times \Delta t$$

$$\Delta x = \frac{1}{2}(v_f + v_i)\Delta t$$

If we substitute equation 1 into equation 2 and simplify, we get equation 3.

This equation is useful if we don't know the final velocity.

Equation 3

$$\Delta x = v_i \Delta t + \frac{1}{2}a(\Delta t)^2$$

Another useful relationship comes from eliminating the time interval Δt. If we rearrange Equation 1 and substitute it into the Δt, we get Equation 4.

Equation 4

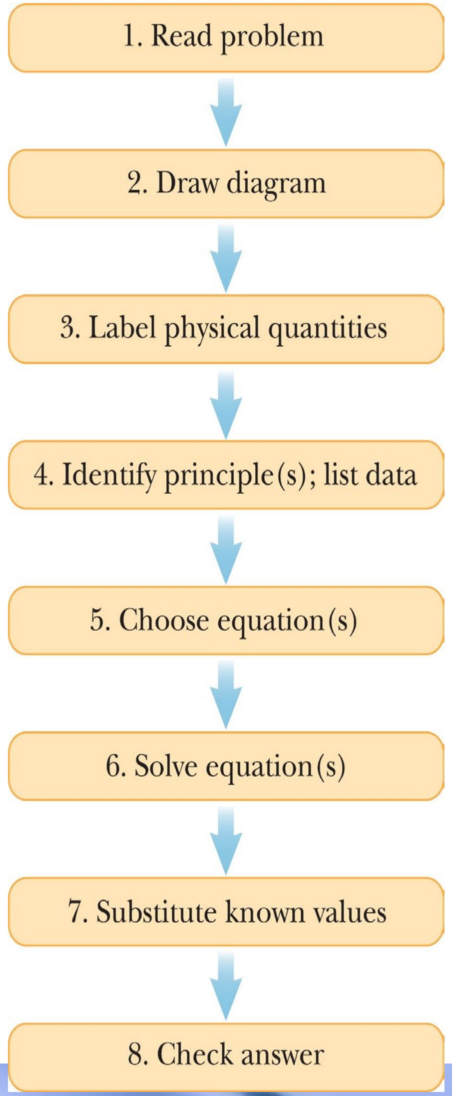
$$v^2{}_f - v^2{}_i = 2a\Delta x$$

One-Dimensional Motion with Constant Acceleration: Problem-Solving Strategy

When solving motion problems, we need a reliable strategy.

There are four steps in our strategy:

1. ***Illustrate the problem***:
    a. Draw a picture of the system
    b. Draw a motion diagram and/or motion graph(s)
2. ***Enumerate the problem***:
    a. Write down the values of all known quantities
    b. List the unknown quantities
3. ***Solve***:
    a. Choose an equation (or equations) that describe the unknowns in terms of the known
    b. Compute the solution
4. ***Validate***:
    a. Check that the answer makes sense in terms of what is known
    b. Check that it is stated with the correct number of significant figures
    c. Check that the units are correct



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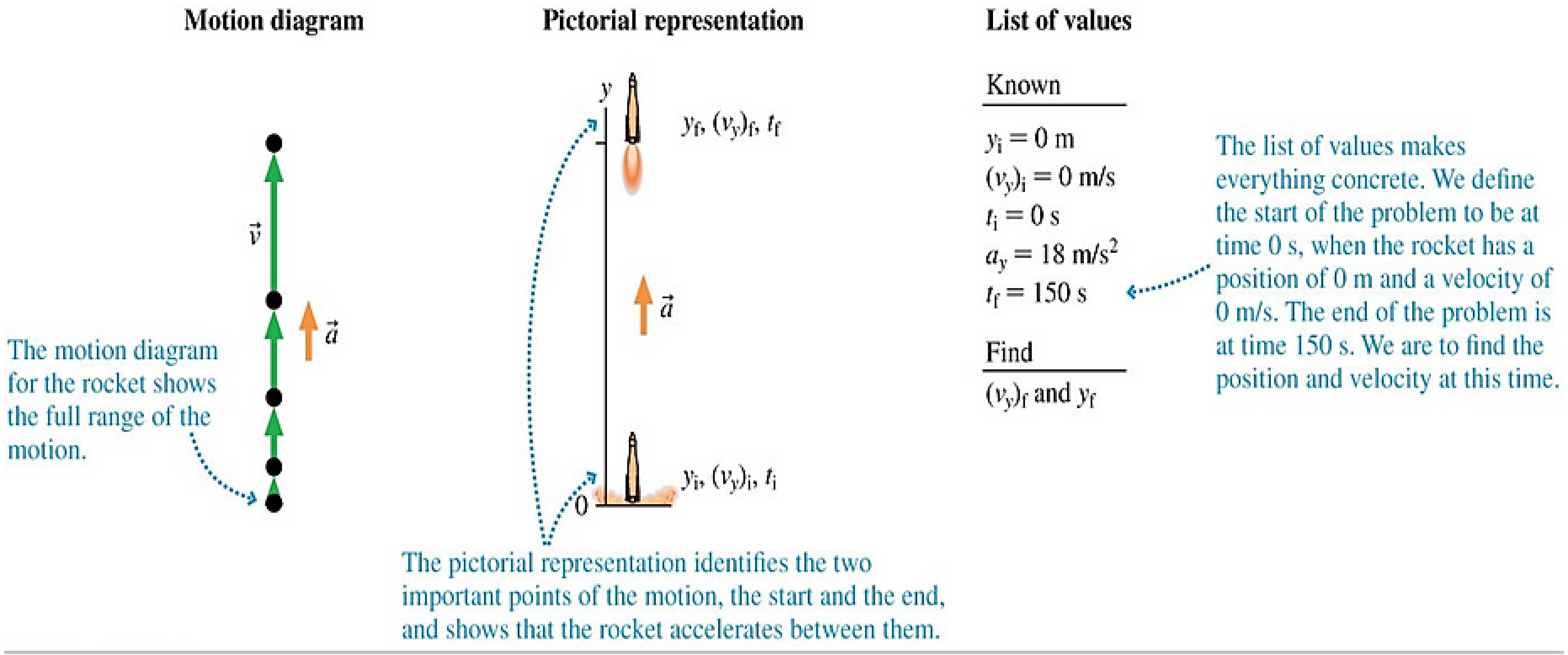
A Saturn V rocket is launched straight up with a constant acceleration of 18 m/s². After 150 s, how fast is the rocket moving and how far has it travelled?



- The first task is to find the final velocity. From what we know in our list of values we can choose a kinematic equation to use. We know the initial velocity, the acceleration, and the time interval, so we can choose Equation 1 from our list of the kinematic equations. Then to find the distance travelled, we can use Equation 4.

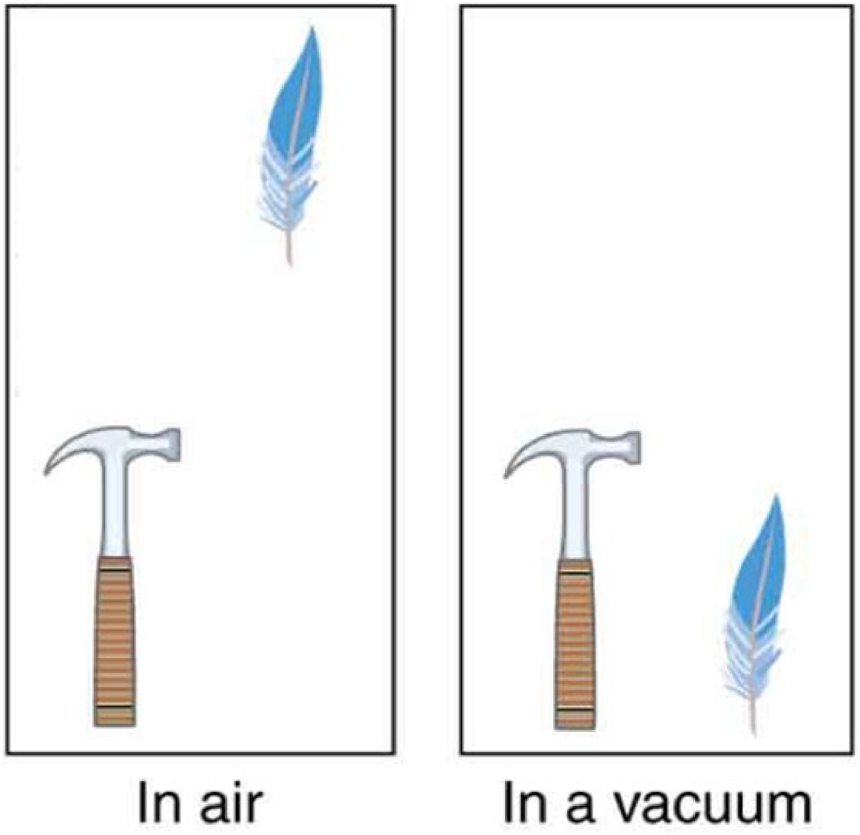
To solve for the final velocity:

$$v_f = v_i + a\Delta t = 0\,m/s + (18\,m/s^2)(150s)$$
$$= 2700\,m/s$$

To solve for the distance travelled:

$$\Delta y = v_i\Delta t + \frac{1}{2}a(\Delta t)^2$$
$$= (0\,m/s)(150s) + \frac{1}{2}(18\,m/s^2)(150s)^2$$
$$= 2.0 \times 10^5 m = 200km$$

Constant acceleration – Free fall



Free Fall

Free fall is a special case of constant acceleration.

Once the coin leaves your hand, it's in free fall, and its motion is similar to that of a falling ball or a jumping gazelle.

We denote the free-fall acceleration due to gravity using the symbol g

At the Earth's surface $g \cong 9.8\ \text{m/s}^2$

Each planet has its own value of g.

Taking the Earth's value as g_E, here are some other values in our solar system

- Moon: $0.16\ g_E$
- Mercury: $0.38\ g_E$
- Saturn: $1.17\ g_E$
- Jupiter: $2.74\ g_E$

Freely Falling Objects

free-fall acceleration:

$$g = 9.80 \text{ m/s}^2$$

kinematics equations:

$$v_y = v_{0y} - gt$$

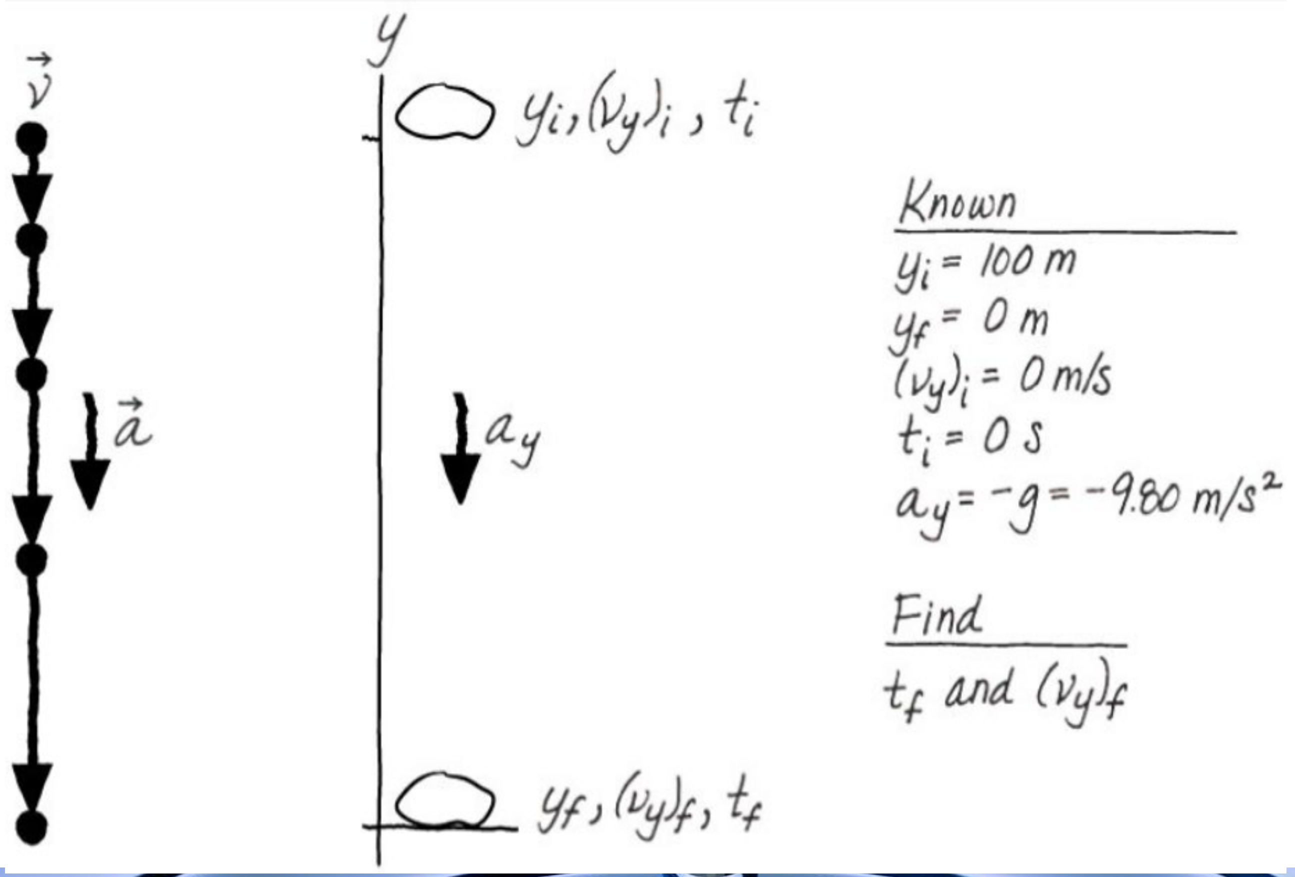
$$\Delta y = v_{0y}t - \frac{1}{2}gt^2$$

$$v_y^{\ 2} = v_{0y}^{\ 2} - 2g\Delta y$$

NOTE: It's conventional to define 'up' as the + y-direction and 'down' as the – y-direction
So in free fall the acceleration is $a = -g = -9.80$ m/s^2.

Free-Fall Worked Example

- A heavy rock is dropped from rest at the top of a cliff and falls 100 m before hitting the ground. How long does the rock take to fall to the ground, and what is its velocity as it hits?



Free-Fall Worked Example

- Free fall is motion with the specific constant acceleration $a_y = -g$. The first question is asking for time so we can use Equation 3 of our kinematic. Using $(v_y)_i = 0$ m/s and $t_i = 0$ s, we find:

$$\begin{aligned} y_f &= y_i + (v_y)_i \Delta t + \frac{1}{2} a_y (\Delta t)^2 \\ &= y_i - \frac{1}{2} g (\Delta t)^2 \\ &= y_i - \frac{1}{2} g {t_f}^2 \end{aligned}$$

We can now solve for t_f:

$$t_f = \sqrt{\frac{2(y_i - y_f)}{g}} = \sqrt{\frac{2(100m - 0m)}{9.8m/s^2}} = 4.52s$$

Now that we know the fall time, we can use Equation 1 to find the final velocity.

$$\begin{aligned} (v_y)_f &= (v_y)_i - g\Delta t = -g t_f = -(9.80m/s^2)(4.52s) \\ &= -44.3m/s \end{aligned}$$

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Topic Summary

One-Dimensional Motion with Constant Acceleration

$$v = v_0 + at \qquad \Delta x = v_0 t + \frac{1}{2}at^2 \qquad v^2 = v_0{}^2 + 2a\Delta x$$

Freely Falling Objects

$$g = 9.8 \text{ m/s}^2$$

$$a = -g$$