Problem Set 3 (2025) - Issued on 11th September 2025, Solutions Webinar on 17th September 2025

1. **Marble in a Fishbowl**
   No calculator
   A 'fishbowl' of height $\frac{4r}{3}$ is formed by removing the top third of a sphere (radius r). The fishbowl is fixed in sand so that its rim is parallel with the ground. A small marble of mass m rests at the bottom of the fishbowl. Assuming all surfaces are frictionless and ignoring air resistance, find the maximum initial velocity that could be given to the marble for it to land back in the fishbowl.

2. **Trusses**
   No calculator, use $g \approx 10\,\mathrm{ms}^{-2}$
   A ball of weight 500 N is suspended from the apex of the structure shown in Figure 1. The structure is made of two trusses, each of length 3.0 m and mass 40 kg. A 3.0 m horizontal rope connects the trusses, tied a sixth of the way up the trusses. If the structure were placed on an ice-rink, calculate the resulting tension in the rope.

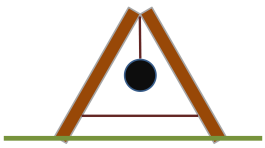

Figure 1: Trusses with a suspended ball

3. **Maximum range**

   (a) Show that the maximum range of a cannon on flat ground is achieved by launching at an angle above the horizontal of $\theta = 45^\circ$.

   (b) Show that, if the cannon is at the top of a hill, with an incline of ϕ, then the range equation can now be written as

$$R = \frac{u^2}{g}\left[\sin 2\theta + \tan\phi\,(1+\cos 2\theta)\right].$$

(c) Determine the relationship between θ and ϕ that maximizes the range.

4. **Monkey-shoot**
A zookeeper needs to tranquilise a monkey who is too shy to come down from the trees, by hitting it with a dart from a tranquiliser gun and catching it in a net as it falls.

   (a) If the monkey does not move, should the zookeeper aim above, at, or below the monkey?

   (b) If the monkey lets go of the branch at the instant the zookeeper shoots the dart, should the zookeeper aim above, at or below the monkey to hit the monkey in midair?

   Once you have decided on your answers to this problem, use SUVAT to confirm them.

5. **Motion-time graphs**
For the following scenarios, sketch the motion-time graphs (displacement-time, velocity-time and acceleration-time).

   - A ball is thrown up in the air and then caught at the same height. Only sketch from the instant the ball leaves the hand to the instant it touches the hand again. Ignore air resistance.
   - A train travels from Birmingham to Oxford, stopping only at Banbury on route. You may assume the journey is in a straight line and it only takes a few minutes of constant acceleration/deceleration to get to its top speed/come to a stop.
   - A football is dropped from a great height (such that it reaches terminal velocity); it bounces in-elastically such that air resistance can be ignored from this point. Sketch the motion from the moment of release until it hits the ground for a second time.

6. **Tangled resistor circuit**
No calculator
If the two circuits in Figure 2 shown are equivalent, what is the value of R_{TOTAL}?

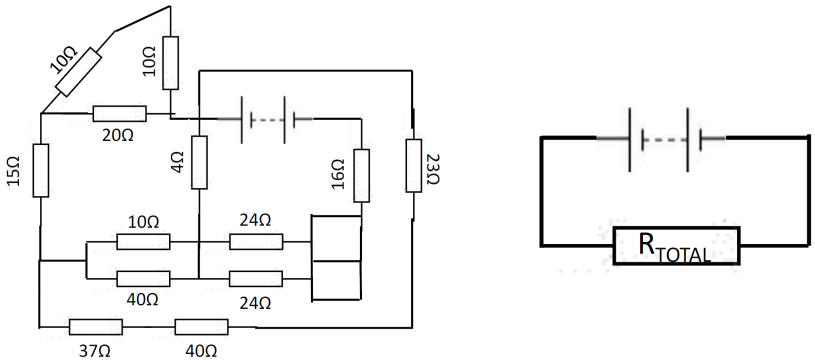

Figure 2: Two resistor networks

7. **Resistor networks**
   A cube of resistors, ABCDEFGH, is made with 12 identical resistors of resistance R, shown in Figure 3 A multimeter probe is used to measure its resistance. One wire is connected to vertex A, and the other probe is moved around the other vertices in turn. Determine the resistance reading in each position.

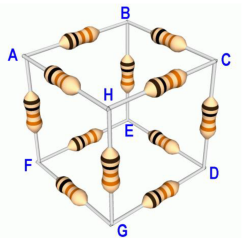

Figure 3: A network of 12 identical resistors of resistance R

Hints for Workshop Session 2

1. **Marble in a Fishbowl**
   Identify the physics principles involved. Draw a large, clear diagram with all key information labelled. Plan your route through the problem. THEN solve.

2. **Trusses**
   Think about how you might be able to simplify the problem. For example: where might be the best place to take moments about? Make sure you

have a clear diagram with all forces labelled.

3. **Motion-time graphs**
   Your intuition will likely mislead you. Start with a free-body force diagram, link this to acceleration, and then link that to velocity and finally displacement. Split the journey up into regions when the behaviour changes.

4. **Monkey-shoot**
   Paul Hewitt has produced a bank of questions designed to test your conceptual understanding of physics. Many of them require 'clever' thinking to solve. By the next study day, you should have tested yourself on all the AS topics. They can be accessed here: https://www.arborsci.com/next-time-questions/.

5. **Maximum range**

   (a) You'll find it helpful for this particular problem to know that

   $$2\sin x \cos x \equiv \sin 2x$$

   In general, follow this step-by-step guide and you'll solve most projectiles problems.

   i. Draw a clear diagram showing all the information given and what you're asked to find.
   ii. Split any velocity vectors (usually given the initial velocity) into horizontal and vertical components.
   iii. Set up sign convention: which horizontal (x) and vertical (y) directions are +ve?
   iv. Write out 2 sets of SUVAT, being careful about minus signs.
   v. The time of flight will be the same in both directions, so you can often find this by resolving vertically and use this to find the horizontal range.

   (b) A clear diagram is always important, more so for tricky problems like this. A stepping stone along the way will be this equation

   $$\frac{1}{2}gt^2 - u\sin\theta t - R\tan\phi = 0.$$

   You'll find it helpful here to know that

   $$\cos 2x \equiv 1 - 2\sin 2x$$

(c) Sorry – there's no clever shortcut here, you're going to have to differentiate! You'll find it helpful here to know that

$$\cot\phi = \tan\left(\frac{\pi}{2} - \phi\right)$$

Your final expression should be reassuringly simple, and it must resemble what you should have found in part 1 when $\phi = 0$.

6. **Tangled resistor circuit**
Redraw the circuit in a more useful/recognizable format, and simplify pairs of resistors as you go. DO NOT try to do it all in one go.

7. **Resistor networks**
What are the symmetries? Re-draw the network in a more familiar format. No net current will flow between points with the same potential.

Numerical answers can be found below.

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1. $\sqrt{\frac{17\pi g}{3}}$; 2. 400 N; 6. 31.5Ω; 7. AB is $R/3$, AC is $R/2$, AD is $5R/6$.