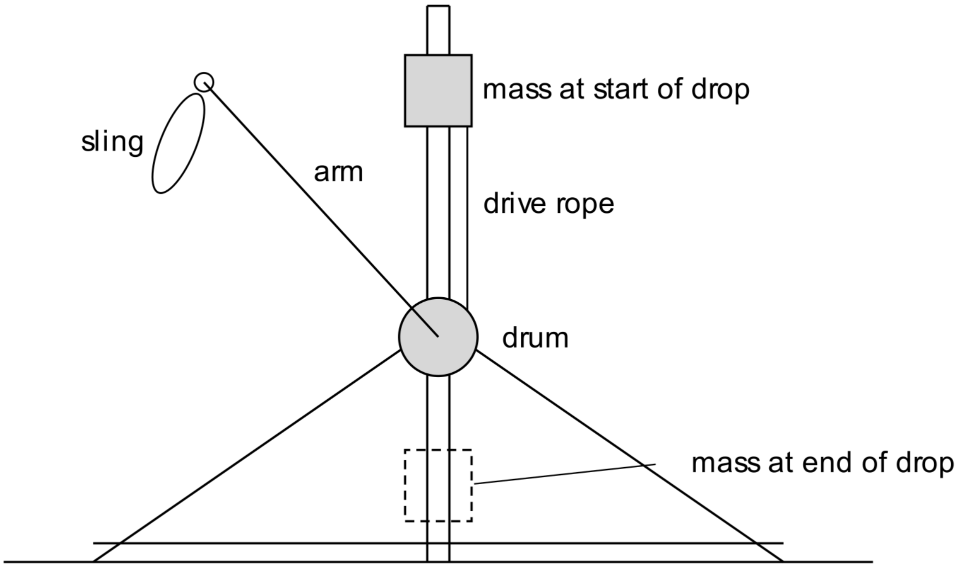
Free practice paper from Fenwick Tutoring. Mark scheme: fenwicktutoring.com/trebuchet-physics-exam

This paper is set around a real machine: a gravity-powered trebuchet built to launch a projectile faster than the speed of sound. Every value needed to answer a question is given in that question or in its figure.



The machine

A mass slides down the mast. A drive rope connects the mass to a drum on the axle of the arm, so the falling mass spins the arm. The sling is wound around the arm as it spins, and unwraps to release the projectile.

You do *not* need to watch the video to answer this paper, but the build is worth watching:

youtube.com/watch?v=Co57SfcT-h0

Answer all questions. A calculator is required for this paper. A clean copy of the physics data booklet is required for this paper. The maximum mark for this examination paper is **[62 marks]**.

1. A trebuchet launches a projectile using a falling counterweight.

A counterweight is released from rest at a height of 2.0 m above the ground. Air resistance is negligible.

(a) Show that the counterweight reaches the ground at a speed of about 6.3 m s^{-1}. **[2]**

....

....

....

....

(b) The counterweight is replaced by one of twice the mass. It is released from the same height.

Explain why it reaches the ground at the same speed. **[2]**

....

....

....

....

(c) Other than air resistance, state **one** assumption made in (a) that does not hold for a real trebuchet. **[1]**

....

....

....

2. In one trebuchet the counterweight does not turn the arm directly. A falling counterweight pulls a drive rope. The rope unwinds from a tapered drum fixed to the axle of the arm.

Figure 1 shows the drum at the start of the launch.

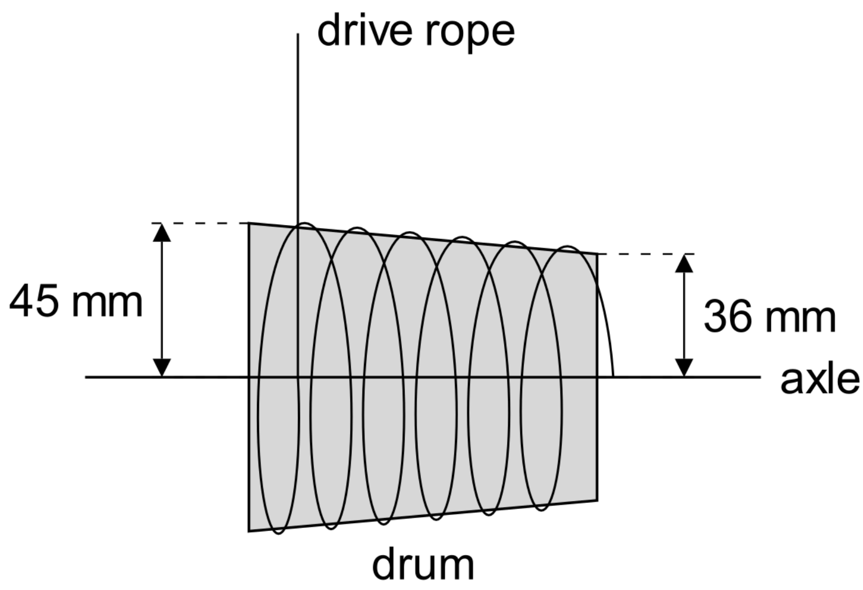


Figure 1

The mass of the counterweight is 10 kg. A pulley system between the counterweight and the drive rope reduces the tension in the rope to one third of the weight of the counterweight.

(a) Determine the tension in the drive rope. **[2]**

....

....

....

....

(b) Determine the torque exerted on the drum by the drive rope at the start of the launch. **[2]**

....

....

....

....

(c) The tension in the drive rope is unchanged at the end of the launch.

Determine the ratio **[2]**

$$\frac{\text{torque at the start of the launch}}{\text{torque at the end of the launch}}$$

3. The rotating assembly of a trebuchet consists of the arm, the axle, the drum and the sling.

The following data are given:

Moment of inertia of the rotating assembly = 0.013 kg m^2

Average resultant torque on the rotating assembly = 1.3 N m

Time from release of the counterweight to release of the projectile = 1.3 s

The rotating assembly starts from rest.

(a) Determine the angular acceleration of the rotating assembly. **[2]**

(b) Determine the angular speed of the arm at the moment the projectile is released. **[2]**

(c) Determine the angular displacement of the arm between the moment the counterweight is released and the moment the projectile is released. **[2]**

(d) Calculate the number of complete rotations the arm makes before the projectile is released. **[1]**

4. The arm of a trebuchet rotates clockwise in a vertical plane about an axle at O. **Figure 2** shows the arm in its initial position.

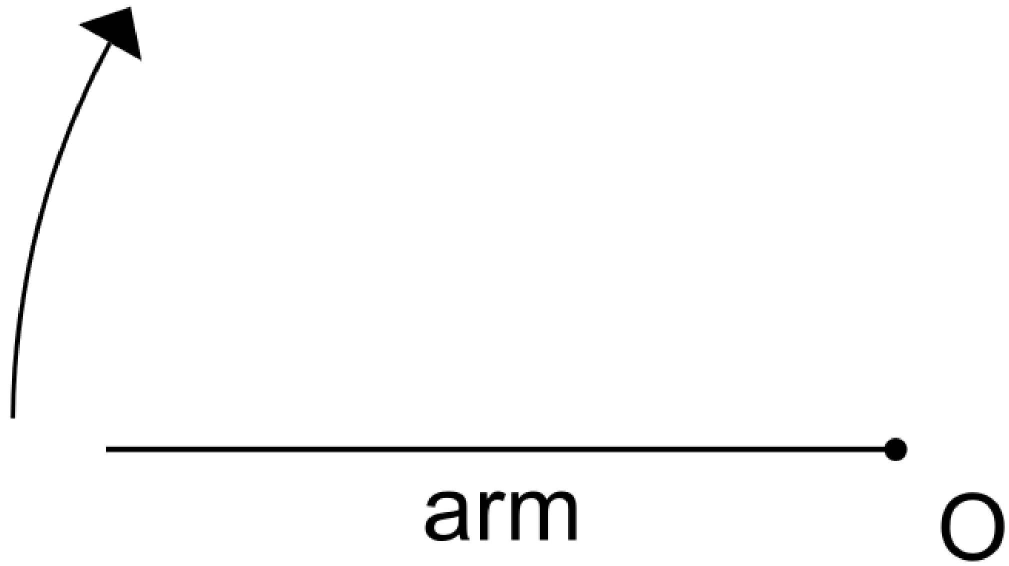


Figure 2

The arm starts from rest. It has a constant angular acceleration of 80 rad s^{-2}. The projectile is released 1.2 s later.

Figure 3 shows the arm at the moment of release. The sling is fully extended in line with the arm. The launch angle of the projectile is *θ*.

Diagram not to scale.

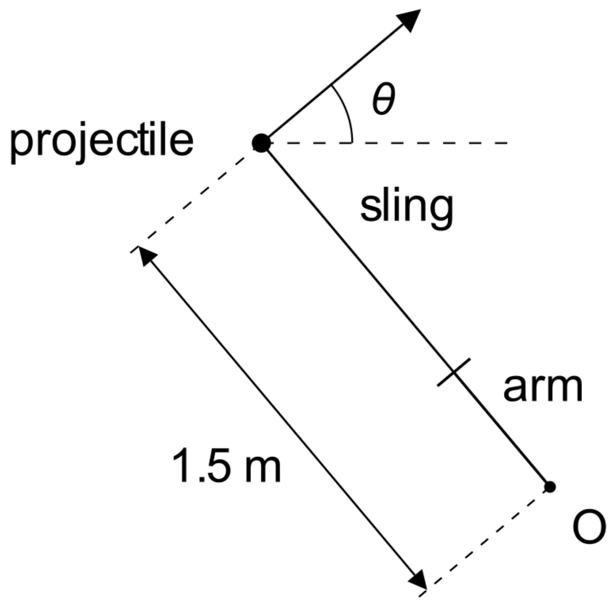


Figure 3

(a) Determine θ. **[4]**

(b) Calculate the speed the projectile would have at the moment of release if it moved with the arm. **[2]**

(c) The projectile leaves the sling at 346 m s^{-1}.

Suggest how this is possible. **[2]**

5. The sling is attached to the arm by a mount at the tip of the arm. The arm is mounted on its axle at O and is held stationary. The mount is pulled by a rope attached to a force meter.

Figure 4 shows the arrangement.

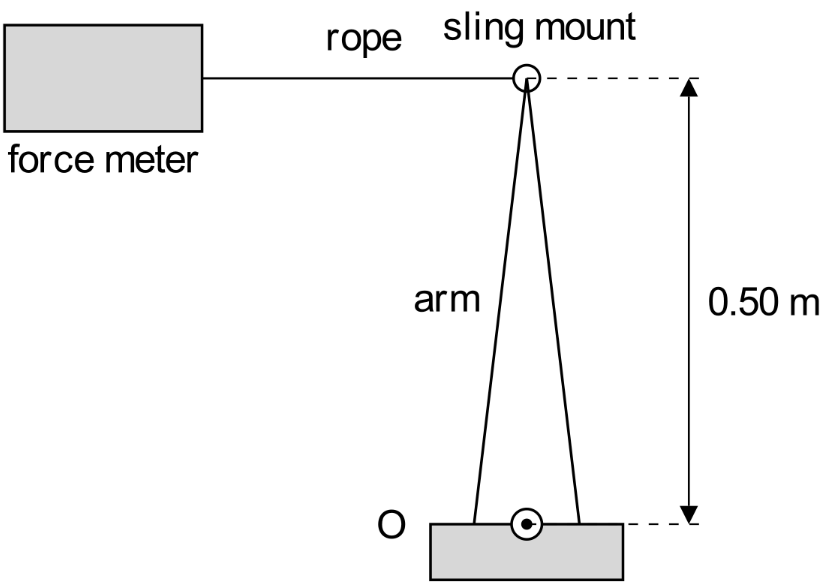


Figure 4

The rope passes through a pulley system that multiplies the force on the mount by three. The force meter reads 200 N.

(a) Calculate the force exerted on the sling mount by the rope. **[1]**

....

....

....

(b) Determine the torque of this force about O. **[2]**

....

....

....

....

(c) The rope is repositioned so that it makes an angle of 30° with the arm. The reading on the force meter is unchanged.

Determine the torque of the force about O. **[2]**

6. A counterweight of mass 10 kg is raised, and is then released to launch a projectile of mass 6.0 g.

The following data are given:

Gravitational potential energy stored when the counterweight is raised = 192 J

Potential energy of the counterweight at the moment of release = 22 J

Kinetic energy of the counterweight at the moment of release = 10 J

Energy stored in the rotating assembly at the moment of release = 78 J

Kinetic energy of the projectile immediately after release = 65 J

Moment of inertia of the rotating assembly = 0.013 kg m^2

Angular speed of the arm at the moment of release = 130 rad s^{-1}

(a) Show that the counterweight is raised through a height of about 2.0 m. **[2]**

(b) Determine the energy dissipated between the release of the counterweight and the release of the projectile. **[2]**

(c) Calculate the rotational kinetic energy of the rotating assembly at the moment of release. **[2]**

(d) Comment on your answer to (c), with reference to the energy stored in the rotating assembly. **[2]**

(e) Calculate the overall efficiency of the trebuchet. **[2]**

7. A trebuchet stands at the edge of a vertical cliff above a horizontal plain. It launches a projectile of mass 4.0 g at 346 m s^{-1} out over the plain.

At the moment of release the projectile is moving in a circle of radius 1.5 m about the axle of the arm.

(a) Determine the magnitude and the direction of the resultant force on the projectile at the moment of release. **[3]**

....

....

....

....

....

Figure 5 shows the path of the projectile.

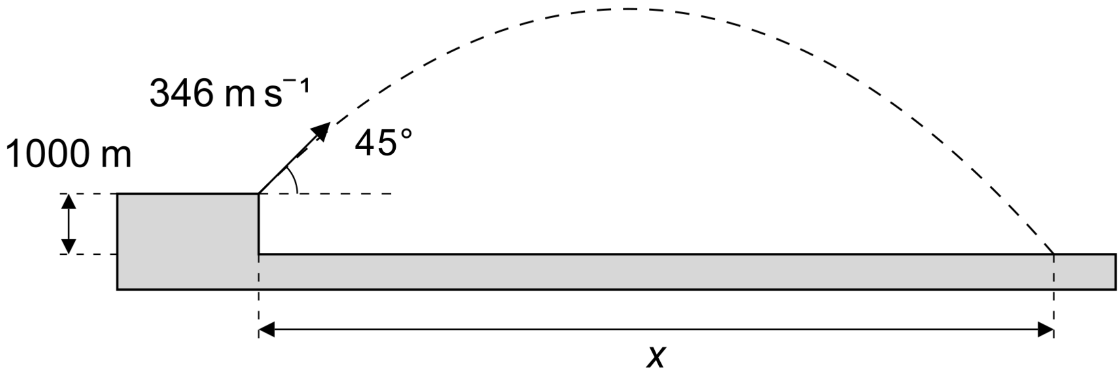


Figure 5

Air resistance is negligible for (b) to (f).

(b) Show that the initial vertical component of the velocity of the projectile is about 245 m s^{-1}. **[2]**

....

....

....

....

(c) Determine the maximum height of the projectile above the plain. **[2]**

(d) Determine the time of flight of the projectile. **[3]**

(e) Determine the distance *x*. **[2]**

(f) Launched at the same speed and angle from ground level, the projectile travels 12.2 km.

Comment on the effect of the cliff on the distance travelled. **[1]**

(g) In an experiment with a real trebuchet the projectile travels a much shorter distance than your answer to (e).

Explain this difference. **[2]**

8. A projectile contains a buzzer that emits sound of constant frequency 2.0 kHz. The projectile is launched at 147 m s^{-1} and travels past a stationary detector.

The speed of sound in air is 343 m s^{-1}.

(a) Determine the difference between the highest and the lowest frequency detected by the detector. **[4]**

(b) A second projectile is launched at 346 m s^{-1}.

Suggest what a detector directly ahead of this projectile detects before the projectile reaches it. **[2]**

Want the mark scheme?

This paper is free to use and free to share. The full mark scheme — with the marking points, the accepted alternatives and the examiner notes on what does *not* earn the mark — is at the link below.

Get the mark scheme at

fenwicktutoring.com/trebuchet-physics-exam

Stuck on any of this?

Rotational dynamics, projectiles from a height and the Doppler effect are exactly the places HL Physics students lose marks they should be keeping. I teach IB Physics one to one, online, and I have been doing it for ten years — whether you are aiming to move a 5 to a 6 or to secure a 7, get in touch.

Book a free introductory lesson at

fenwicktutoring.com/contact

Written by James Fenwick, Fenwick Tutoring. More free practice material and revision simulations at fenwicktutoring.com.