Making Lead Shot

An Introduction to Mechanics

This problem provides an introduction to mechanics.

Intended Learning Outcomes

By the end of this activity students should be able to:

- Define velocity and acceleration
- Use constant acceleration formulae
- Define equilibrium as the balance of forces
- Use Newtonian equations of motion to compute the behaviour of bodies subject to unbalanced forces
- Use graphical representation and explain the advantages of so doing
- Demonstrate a knowledge of conservation of energy and momentum and their use in applications
- Solve problems involving work and power
- Use dimensional analysis to derive simple relationships

KEYWORDS:

Conservation of energy, conservation of linear momentum, dimensional analysis, dynamics, energy, equations of motion, forces, graphical representation, gravity, kinematics, kinetic energy, linear acceleration, linear momentum, Newton's Laws, point particles, potential energy, power, velocity, work, work done.

Contents

Reading List

The following textbooks are suggestions, other equivalent textbooks are available:

- Breithaupt, J. ***Physics***. Palgrave Foundations.
- Tipler, P.A. ***Physics for Scientists and Engineers***. Freeman.

This problem is adapted from an on-line knowledge enhancement module for a PGCE programme. It is used to cover the kinematics and dynamics of point particles.

Problem Statement

The lead shot used in shotgun cartridges consists of small spherical pellets 2-3mm in diameter and this is made by pouring molten lead through a frame suspended in a high tower, a method that has been used since its invention by William Watts in 1782. Now in order to produce spherical shot the lead has to solidify before the pellet has reached its terminal velocity. How high should we build the tower?

A shot tower at Redcliff, Bristol.
Photo by Yellow Book Ltd (http://www.flickr.com/people/yellowbookltd/)

Suggested Deliverables

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Questions for Class Discussion

1. In terms of mass, length and time, what are the dimensions of (i) energy (½ mv^2), (ii) pressure (Force/area)

2. What are the SI units of (i) energy (½mv^2), (ii) pressure (Force/area)

3. What is 90 mph in ms^{-1}? (Use 1km = 5/8 mile) (enter only the numerical value without units)

4. The diffraction of a beam of light by a circular aperture produces a spot that has a size depending on the wavelength of light, the radius of the aperture and the distance between the screen and the aperture. Despite the fact that the problem involves just three parameters, dimensional analysis cannot be used to determine the size of the spot. Why not? (No knowledge of the behaviour of light is required to answer this question.)

5. Match the quantities in the set (a), (b), (c) to those in the set (i), (ii), (iii) by balancing the dimensions (c = speed of light, G = Newton constant Nm^2kg^{-2})

   (a) the lifetime *t* of a black hole of mass *M* and radius *R*
   (b) the energy per second *L* radiated in gravitational radiation by a body of mass M in an orbit of radius R
   (c) the escape speed from a planet of mass *M* and radius *R*

   (i) $M^3c^6G^4$
   (ii) $G^{1/2}M^{1/2}/R^{1/2}$
   (iii) $G^4 M^5 / c^5 R^5$

6. If a sprinter who clocks 10 s for the 100m were to be accelerating at a constant rate, how fast in ms^{-1} would he be traveling across the finish line

7. How do the constant acceleration formulae relate to Newton's 2nd law?

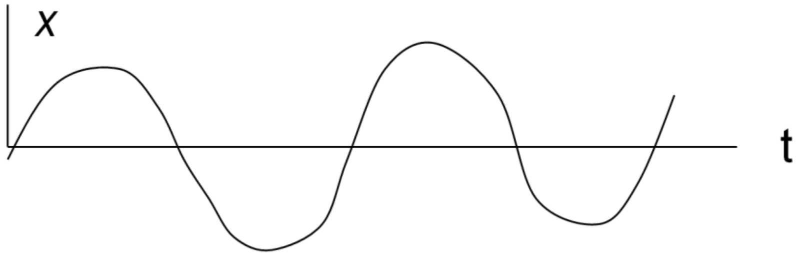
   (a) They are logically independent because they describe kinematics, not dynamics
   (b) They are equivalent in the special case of a constant force
   (c) Constant acceleration is not possible in practice

8. At what point do astronauts become weightless?

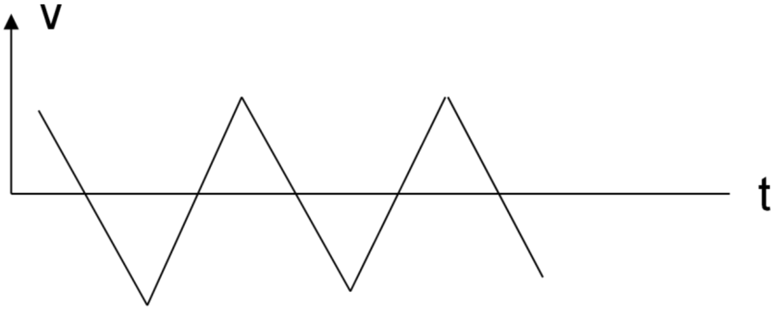
   (a) In orbit
   (b) As soon as the rocket motors are switched off
   (c) as soon as they leave the ground
   (d) never

9. Match the equation of motion $\frac{d^2x}{dt^2} = -x$ to a displacement-time graph.

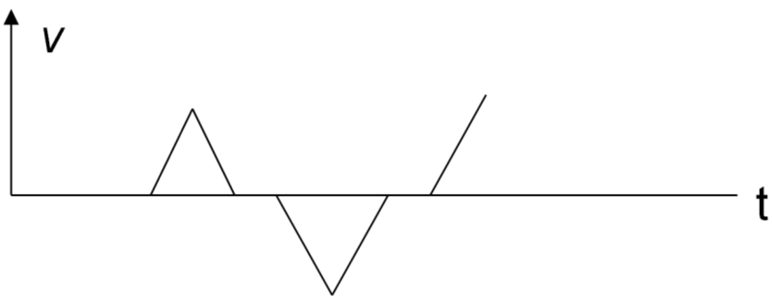
(a)



(b)

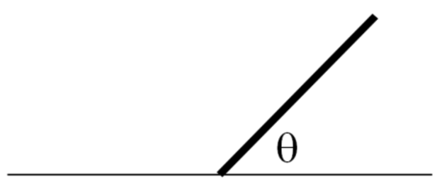


(c)



10. Arthur C Clarke suggested that high g-forces could be reduced to zero by immersing a body in a fluid at neutral buoyancy. Is this true? YES/NO

11. What is the gravitational PE of the rod of mass m in the picture?



12. Can a perfectly elastic body suffer damage in a collision?

Individual Exercises

1. Use dimensional analysis to determine how the period of a pendulum depends on its length.

Foucault's Pendulum
Photo by Ben Owtrowsky (http://www.flickr.com/people/sylvar/)
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2. A Dept of Transport information film shows how much the stopping distance of a car travelling at 35 mph is increased over one travelling at 30 mph for the same deceleration. It might have more impact to show the speed of impact instead. Suppose a car can just brake from 30 mph to stop short of a pedestrian. What would be the speed at impact in braking from 35mph? Would this make people aware of the dangers of speed?

3. Drag racers accelerate from rest at constant power over a straight course and the one with the highest terminal velocity wins. How does the terminal speed depend on the power of the car?

4. Criminals prefer light weight guns because they are more easily concealed. Why are they in more danger of hurting themselves when firing such a gun?