Chapter 1: Energy

Lesson 1.1 Potential energy

1 You would feel that the force needed to stretch the rubber band increases, the more you stretch it.

2 As you turn the key, you stretch the spring more. This means that the energy stored increases.

3 Gravitational potential energy changes when the height changes. Since the aircraft is travelling horizontally, its height stays the same so there is no change in gravitational potential energy.

4 $E_p = mgh = 300 \times 10 \times 2 = 6000$ J

5 Mass of ball $m = 60 \div 1000 = 0.06$ kg.

$E_p = mgh = 0.06 \times 10 \times 2 = 1.2$ J

6 $E_e = ½\ ke^2 = 0.5 \times 300 \times 0.1^2 = 1.5$ J

7 Extension = 25 – 20 = 5 cm = 0.05 m

$E_e = ½\ ke^2 = 0.5 \times 500 \times 0.05^2 = 0.625$ J

8 $E_e = ½\ ke^2$ so $k = 2E_e / e^2 = (2 \times 12) / 0.16^2 =$ 937.5 N/m

9 $E_e = ½\ ke^2 = 0.25$J

So $0.5 \times 200 \times e^2 = 0.25$

$e^2 = 0.25/100 = 0.0025$

Therefore e = 0.05m = 5cm.

The total length of the spring = 20cm, which means that the unstretched length = 20 – 5 = 15cm.

Lesson 1.2 Investigating kinetic energy

1 The amount of energy in the kinetic energy store depends on both the mass and the speed. An adult has more mass than a child so they would have more kinetic energy even though the speed is the same.

2 The fuel is the food that the child has eaten.

3a $E_k = ½\ mv^2 = 0.5 \times 50 \times 2^2 = 100$ J

3b Her kinetic energy would be four times as much.

4 Kinetic energy stored at 10 m/s = $0.5 \times 1200 \times 10^2$ = 60 000 J

Kinetic energy stored at 30 m/s = $0,5 \times 1200 \times 30^2$ = 540 000 J

So kinetic energy increases by 540 000 – 60 000 = 480 000 J

5 240 km / h = (240 × 1000 m) / 3600 s = 66.7 m/s

6a When the ball is at the highest point.

6b As the ball hits the surface for the first bounce

7 After you let go of the ball and the ball is moving upwards, energy stored in the ball's kinetic energy store is being transferred to energy stored in the gravitational potential energy store.

8 E_p stored by the ball at 20m = $mgh = 2 \times 10 \times 20 =$ 400 J

So E_k ball stores at the ground = 400 J

$½\ mv^2 = 400$

So $0.5 \times 2 \times v^2 = 400$

$v^2 = 400$

so v = 20 m/s

Lesson 1.3 Work done and energy transfer

1 The amount of force and the distance that the force moves.

2 The gravitational force (weight) on the person as the person moves towards the ground.

3 $W = F \times s = 400 \times 1.5 = 600$ J

4 She is not doing any work as the force is not moving.

5 $W = F \times s$, so $s = W / F = 300 / 200 = 1.5$ m

6 $W = F \times s$, so $F = W / s = 3000 / 12 = 250$ N

7a $E_k = ½\ mv^2 = 0.5 \times 800 \times 12^2 = 57\ 600$ J

7b $F = W / s = 57\ 600 / 8 = 7200$ N

8a $W = F \times s = 500 \times 4 = 2000$ J

8b 2000 J (assuming all of the energy in her E_p store is transferred to her E_k store)

8c E_k reduces by 2000 J so work done by the trainers = 2000 J.

$F \times s = 2000$ so $F \times 0.01 = 2000$.

$F = 2000 / 0.01 = 200\ 000$ N.

Lesson 1.4 Understanding power

1 The kettle

2 Although the television is less powerful than the food blender, it might be operating for a much longer time.

3 2 minutes = 2 × 60 = 120 seconds.

$P = W / t = 108\ 000 / 120 = 900$ W

4 $W = P \times t = 2000 \times 30 = 60\ 000$ J

5a $W = F \times s = 4000 \times 6 = 24\ 000$ J

5b $P = W / t = 24\ 000 / 20 = 1200$ W

6a $W = F \times s = 800 \times 5 = 4000$ J

6b $P = W / t$ = 4000 / 10 = 400 W

7 15 minutes = 15 × 60 = 900 s

Work done = gain of $E_p = mgh$ = 60 × 10 × 300 = 180 000 J

$P = W / t$ = 180 000 / 900 = 200 W

8 10 cm = 0.1 m

Work done for each step up = gain of $E_p = mgh$ = 60 × 10 × 0.1 = 60 J

So total work done = 60 × 20 = 1200 J

$P = W / t$ = 1200 / 30 = 40 W

9a 108 km /h = 108 000 m / 3600 s = 30 m/s.

So the distance the car travels in 1 second = 30 m.

9b Work done for 1 second = $F \times s$ = 1000 × 30 =

30 000 J.

P = W / t = 30 000 / 1 = 30 000 W = 30 kW.

Lesson 1.5 Specific heat capacity

1 The material with the bigger increase of temperature does not need as much thermal energy transferred to it to increase its temperature by 1 ^{0}C.

2 $\Delta E = mc\Delta\theta$ = 1 × 380 × 20 = 7600 J

3 $\Delta E = mc\Delta\theta$ = 2 × 450 × 30 = 27 000 J

4 Water has a very high specific heat capacity. This means that the water can transfer lots of thermal energy to the bed as it cools down – making the bed warmer.

5 It is the thermal energy needed to raise the temperature of 1 kg of a substance by 1 ^{0}C.

6 $\Delta E = mc\Delta\theta$ = 3 × 450 × 15 = 20 250 J

7 $\Delta\theta$ = 30 – 10 = 20 ^{0}C

$\Delta E = mc\Delta\theta$ = 50 × 800 × 20 = 800 000 J

Concrete is chosen as it has a relatively high specific heat capacity so it can store more thermal energy than most other solids.

8 Change in thermal energy of the steel =

1 × 450 × (80 – θ) = 36 000 – 450 θ

Change in thermal energy of the water = 0.5 × 4200 × (θ – 10) = 2100 θ – 21 000

So 36 000 – 450 θ = 2100 θ – 21 000

So 2550 θ = 57 000

θ = 22.4^0

Lesson 1.6 Required Practical: Investigating specific heat capacity

1 Stir the water and measure the new temperature of the hot water + brass with the thermometer.

2 Subtract the new temperature of the hot water + brass from the initial temperature of the hot water (~ 80^{0}C)

3 Subtract the temperature of the ice-cold water + brass (0 ^{0}C) from the new temperature of the hot water + brass.

4 The temperature would decrease as thermal energy would be transferred to the surroundings.

5 The brass might warm up as you move it. You would assume that the brass changed temperature more than it actually did when you added it to the hot water. This would mean that your measurement of the specific heat capacity would be too small.

6 The temperature of the brass and hot water would steadily decrease as heat energy is being transferred to the surroundings.

7 You need to transfer the brass as quickly as possible and you also need to measure the new temperature of the hot water + brass as quickly as possible (making sure that all of the thermal energy transfer from the hot water to the brass had taken place).

8 In your calculation, you assume that all of the thermal energy transferred to the brass has come from the water rather than the surroundings.

9 $\Delta E = mc\Delta\theta$ = 0.25 × 4200 × (26 – 17) = 9450 J

10 9450 J

11 The temperature would decrease from 100 ^{0}C to 26 ^{0}C, so $\Delta\theta$ = 100 – 26 = 74 ^{0}C.

12 $c = \Delta E / (m\Delta\theta)$ = 9450 / (0.6 × 74) = 213 J/kg ^{0}C

13 The brass is likely to cool down as it moves from the boiling water to the cold water. Therefore the temperature change of the brass as it is heating the cold water up is likely to be less than 74 ^{0}C. This would result in the calculation in question 12 becoming a larger value.

Lesson 1.7 Dissipation of energy

1 Lubricate the wheels to reduce the effect of friction.

2 Newspaper reduces the amount of thermal energy that is transferred through it in any direction. Therefore, it reduces the thermal energy transferred to a cold ice cream as much as the thermal energy transferred away from the fish and chips.

3 Most thermal energy is lost through the windows. You could draw the curtains / use double glazing as this would reduce the rate that the thermal energy conducts.

4 The eco home needs to be well insulated so that it reduces the amount of thermal energy it loses to a bare minimum. It can do this by having thick walls with cavity wall insulation, thick loft insulation, triple glazed windows.

5 The thermal energy dissipates into the surroundings. This means that it spreads out and becomes diluted. The energy is too thinly spread for us to collect it again to re-use.

6 Energy is transferred to the surroundings and the car itself as thermal energy. Energy is also transferred into sound energy and gravitational potential energy if the car is going uphill.

7 Energy is being transferred to the thermal energy stored in the surroundings. Here the energy is dissipated which means it becomes very spread out and the temperature of the surroundings does not increase by very much (shown by the dark blue colour of the sky). Energy is being transferred more quickly through the windows than through the walls of the buildings because the windows are not as thick and they have a higher thermal conductivity. The ground floors of the buildings are transferring thermal energy more quickly than the higher floors. This is probably due to the ground floors storing more thermal energy as they have been heated more than the upper floors (since people have been there during the day).

Lesson 1.8 Energy efficiency

1 It heats up the surroundings. However, the temperature increase of the surroundings is very small as the energy has become very spread out.

2 An electric motor does not get as hot as a petrol or diesel engine as there is no need to convert energy from the fuel into thermal energy. Therefore, much less energy is wasted by transferring energy into the thermal energy stored in the surroundings.

3 Efficiency = useful energy output / total energy input = 80 / 100 = 80 %

4a Efficiency = useful energy output / total energy input = 135 / 500 = 0.27 = 27 %

4b Not all of the coal is burned.

5 Some of the energy is transferred to the thermal energy stored in the kettle and the surroundings rather than the thermal energy stored in the water.

6 Efficiency = useful energy output / total energy input

0.65 = useful energy output / 200

So useful energy output = 0.65 × 200 = 130 J.

7 Energy cannot be created or destroyed, only transferred from one store to another.

8 The metal expands so some of the energy is transferred to the elastic potential energy stored in the metal.

9 Some of the energy is transferred to the thermal energy store of the eardrums; some of it is transferred to the thermal energy stored in the air; some of the sound reflects back off your eardrums; the energy spreads out so not all of the energy transferred by the sound ends up at your eardrums.

10 First calculate the total energy input to the car:

Total energy input = useful energy output (× 100) / efficiency = 100 × 100 / 85 = 117.6 J

Now calculate energy input at the power station using the same formula:

Total energy input = 117.6 × 100 / 35 = 336 J.

Lesson 1.9 Required Practical: Investigating ways of reducing the unwanted energy transfers in a system

1 Tazim is correct to say that only metals are good thermal conductors but other materials are also able to conduct a little. Different materials conduct differently so it is likely that all the materials will have different insulating effects. So Tazim's statement is incorrect.

2 The type of insulating material in the box; the amount / thickness of insulating material; the size / surface area of the box; the colour of the surfaces of the box; the material the box is made out of; the temperature of the surroundings; initial temperature of the liquid.

3 e.g. the better that an insulating material traps air then the better insulator it is and the hotter the liquid will be after a certain period of time. So expanded polystyrene would be the best insulator and air would be the worst.

4 Variables that need to be kept the same: size and shape of the box; thickness of insulating material (by making sure the box is completely packed full of the insulating material); the initial temperature of the liquid; the volume of the liquid; the time interval between measuring the initial temperature and the final temperature of the liquid.

Variables to change: the insulating material

Variables to measure: the initial temperature of the liquid, the temperature of the liquid after a certain amount of time.

Method:

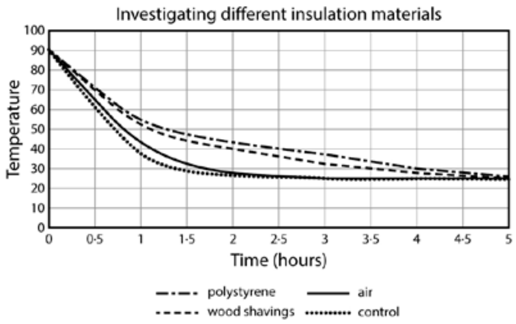
Pour 300 ml of boiling water into the cooking pot and wait for the temperature to decrease to 90.0 ^{0}C. Start a stopwatch to measure the time.

Then place the lid on the pot and place the pot in the box as quickly as possible (for the control, take the measurements without putting the pot in the box).

Pack in the insulating material as quickly as possible and make sure that sure the box is fully packed.

Every hour (up to 5 hours) take the pot out of the box and record the temperature of the water with a thermometer. Put the pot back into the box and repack the insulating material as quickly as possible.

5



6 The gradient of the graph – the line with the shallowest slope indicates the best insulator.

7 The liquid becomes almost the same temperature as the surroundings so it only cools very slowly.

8 The rate of cooling is the gradient of the graph.

9 The rate of cooling depends on the difference in temperature between the liquid and the surroundings. During the first hour, the temperature difference was large so the rate of cooling was high; during the fifth hour the temperature difference was small so the rate of cooling was low.

10a No matter how good an insulating material is the pot would end up as cold as the room eventually. It is the time it takes to do this that matters. The experiment showed that the different insulators had different rates of cooling so it was able to test the hypothesis.

10b This is correct. A larger mass of liquid would mean that the liquid takes longer to cool down but the experiment is only meant to investigate how the type of insulating material affects the rate of cooling.

10c The box is trapping the air inside so this is a different situation from when the pot is open to the atmosphere where the air can move around freely. You can see from the graph that the air was able to insulate the pot a little bit better when it was trapped inside the box.

10d Some lines (such as the control) cooled down to their final temperature much sooner than five hours. So if you drew a straight line from 90 ^{0}C to 25 ^{0}C at the time when the graph reached this temperature then the lines would have different gradients – showing that the materials have different insulating properties.

11a The energy transferred, $\Delta E = mc\Delta\theta$. Since m and c remain the same then the amount of energy transferred depends on the temperature change, $\Delta\theta$.

For air: $\Delta\theta$ = 90.0 – 43.5 = 46.5 ^{0}C

For polystyrene: $\Delta\theta$ = 90.0 – 55.0 = 35.0 ^{0}C.

46.5 / 35.0 = 1.33

11b For air: $\Delta\theta$ = 43.5 – 28.0 = 15.5 ^{0}C

For polystyrene: $\Delta\theta$ = 55.0 – 43.5 = 11.5 ^{0}C

15.5 / 11.5 = 1.35

Lesson 1.10 Using energy resources

1a e.g. a motor, an electric car, a fan

1b e.g. a lift, an escalator, a drone

2 e.g. coal or wood in a fire, gas in a boiler in a central heating system, solar power in a solar cooker

3 Energy from your food, which originally comes from the Sun.

4 It is easy to install wires above the train tracks that can connect up the train to an electricity supply. It would be very difficult and expensive to install wires that aircraft could use while flying. The aircraft have to carry their energy with them.

5 Any two from: wind, wave, hydroelectric, solar, geothermal, tidal, nuclear.

6 Only some countries are surrounded by water where the waves a large and reliable enough to provide useful amounts of energy.

7 When satellites orbit the Earth they spend part of their orbit in sunlight and the other part in the dark. The solar panels will only provide energy when they are in the sunlight. Therefore, they need to charge up a battery which is able to provide energy to the satellite when it is in the dark.

8 We can plant new trees. As long as the trees produce new wood at the same rate that we use it, then the energy resource is always replenished.

9 Nuclear fuel.

10 Bio-fuels are being replenished at the same rate that they are being used. Fossil fuels were formed over millions of years and we are burning them at a considerably faster rate than they are being created. Therefore, they are running out.

11a **Energy** is the capacity to do work. It is transferred from one energy store to another when an object is doing work. An **energy resource** stores energy in a form where it can easily be transferred to another energy store and thus do useful work.

11b Energy is always conserved because it always gets transferred from one energy store to another energy store – it never just disappears. An energy resource is not conserved since the energy it stores is transferred to other energy stores.

When energy is transferred it usually becomes less useful because some of it is dissipated into the thermal energy stored in the surroundings.

Lesson 1.11 Global energy supplies

1 They are non-renewable resources and so will run out.

2 Coal. The worldwide use of coal dramatically increased between 2000 and 2010 and this is when China's energy use grew rapidly.

3 Although fossil fuels will eventually run out and that there are environmental problems, the world's energy needs to come from somewhere. Renewable energy is unable to meet the demand at present.

4 Environmental considerations: This will release carbon dioxide and sulfur dioxide into the atmosphere which will contribute to global warming and acid rain.

Political considerations: People might not vote to elect the council again if they are angry with the plan.

Ethical considerations: It is not morally right to destroy a beautiful part of the country or harm the health of people in the future.

Social considerations: It might give more people jobs but it might adversely affect the health of lots of people.

Economic considerations: It would bring more income to the area but it might cost a lot of money to set it up.

5 The motor does not burn fuel so the only heat it creates is due to friction. Therefore, less energy is wasted.

6 Efficiency = 80% = 0.8. Input power = output power / efficiency = 3/0.8 = 3.75 kW.

7 The power station needs to provide 3.75kW. Therefore, it needs an input power of 3.75 / 0.4 = 9.375 kW. So the overall efficiency = output power / input power = 3 / 9.375 = 0.32 or 32%. This is less efficient than a diesel engine.

8 Make the car more streamlined; make the car lighter; drive the car with less accelerating and breaking; make sure the moving parts are well lubricated; make sure the tyres are in good condition.

Lesson 1.12 Key Concept: Energy transfer

1 All of these are storing energy. The ball is storing kinetic energy, the string is storing elastic potential energy, the hot object is storing thermal energy and the mixture of oxygen and fuel is storing chemical energy.

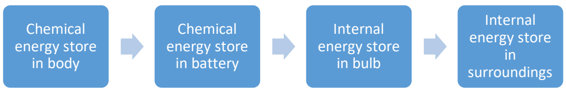
2a The ball could transfer kinetic energy by colliding with another object. This has limited use but is used in e.g. marble runs, an aid to ten pen bowling, Rube Goldberg machines.

2b The spring could transfer energy from its elastic potential energy store to its kinetic energy store. This is a useful energy transfer in some mechanical clocks and watches or in other clockwork devices.

2c The hot object could transfer energy to the thermal energy stored in the surroundings – for example in a hot water bottle or the heating element in a toaster or kettle.

2d The mixture of oxygen and fuel can transfer energy from its chemical energy store to a thermal energy store. This is used in engines such as rockets.

3



4a Chemical energy store in body decreases; kinetic energy store of bicycle increases (if bicycle is accelerating); gravitational potential energy store of the bicycle increases (if bicycle is going uphill); internal energy of the surroundings increases (since the cyclist needs to do work against air resistance and friction).

4b Chemical energy store in match decreases; thermal energy store of surroundings increases.

5 The amount of energy is represented by the number of bricks. No matter what the child does to the bricks and if one becomes lost – the total number of bricks remains the same.

6 The system must include the surroundings as all of the chemical energy in the coal ends up in the internal energy of the surroundings once the train has stopped.

Lesson 1.13 Maths Skills: Calculations using significant figures

1 $E_p = mgh$

E_p = 70.0 kg × 9.8 N/kg × 2.0 m

= 1372 J = 1400 J (to 2 significant figures)

2 $E_p = mgh$

E_p = 0.0500 kg × 9.8 N/kg × 10.0 m

= 4.9 J = 4.90 J (to 3 significant figures)

3 $E_e = ½ke^2$

= 0.5 × 350 N/m × 0.09^2 m^2

= 0.14175 J = 0.14 J (to 2 significant figures)

End of Chapter Questions

1 d) The second one will transfer energy more quickly. [1 mark]

2 efficiency = useful output energy transfer (× 100) / total input energy transfer [1 mark] (Allow answer without the (× 100) and/or using the word “power” instead of “energy”)

3 An energy resource that will eventually run out. [1 mark]

4 c) dissipating [1 mark]

5 elastic potential energy is the energy stored when something is stretched or compressed [1 mark] whereas gravitational potential energy is the energy stored when something is moved vertically upwards (and work is done against the pull of gravity) [1 mark]

6 c) They have the same amount of stored thermal energy. [1 mark]

7 150 W, 0.1 kW, 0.08 kW, 60 W, 15 W. [1mark]

8 $W = F \times s$ [1 mark] = 400 × 2 = 800 J [1 mark]

9 a) Its colour. [1 mark]

10 Air is a poor conductor of heat / good insulator [1 mark]. The bubble wrap has lots of trapped air in it [1 mark].

11 Energy is stored in the thermal energy store of the fish and chips [1 mark]. Since the fish and chips are hotter than the surroundings then some of this energy will transfer to the thermal energy store of the surroundings [1 mark].

12 The temperature of the roof is higher than most of the rest of the house [1 mark]. This is probably because the energy is transferring upwards (since heat rises) [1 mark].

13 Energy transfers from the gravitational potential energy store of the cat [1 mark] to the kinetic energy store of the cat as it falls [1 mark]. The energy transfers to the thermal / internal energy of the surroundings as the cat hits the ground [1 mark].

14 It transfers 2000 J of energy every second. [1 mark]

15 ΔE stands for the change in energy / the energy transferred to the object’s thermal energy store; m stands for the mass of the object; Δθ stands for the change in temperature of the object. [1 mark]

16 The night storage heaters need to be able to store a large amount of thermal energy so they can keep on heating the house throughout the night [1 mark]. Objects with a high specific heat capacity store a large amount of thermal energy at a particular temperature [1 mark].

17 Level 3: A clear and logical description is made in a coherent sequence of steps. The procedure would lead to a successful conclusion and methods for ensuring a fair test are discussed. There is some valid comment about safety precautions that should be carried out. (5-6 marks)

Level 2: An experiment is outlined that would lead to a successful conclusion although detail is missing such as what measuring instruments should be used. The need for a fair test and safety precautions are covered although they are not coherently linked to the procedure. (3-4 marks)

Level 1: Some of the ideas are covered but there is not a full description and there is not a logical sequence of ideas. (1-2 marks)

Indicative content

- A method for heating one end of the rod (e.g. by using a Bunsen burner)
- A method for measuring the temperature of the other end of the rod (e.g. by using a thermometer or using a pin stuck on to the end of the rod with wax)
- A method for timing to reach a certain temperature (or for the pin to fall off due to the wax melting)
- The material with the shortest time would have the highest thermal conductivity
- A method to ensure a fair test (e.g. rods same thickness and length / temperature of Bunsen flame is kept the same)

Precautions to ensure that the experiment is safe (e.g. tie hair back, wear safety spectacles, avoid touching the rods if they are hot or use heat proof gloves).

18 Temperature is a measure of how hot something is [1 mark]. Thermal energy is the capacity of the

object to do work by transferring this energy into other forms [1 mark].

So temperature is a measure of the *ability* of an object to transfer thermal energy and do work whereas thermal energy is the *amount* of work the object can do by transferring its energy.

19 Energy cannot be created or destroyed [1 mark]. So energy lost in one energy store is transferred to another one [1 mark].

20 Level 3: The data is linked to a numerical calculation of efficiency to show that a higher bounce height results in a higher efficiency. Several limitations of the experiment are evaluated including experimental techniques and the quality of the data and it is clearly justified whether the student's conclusion is valid. (5-6 marks)

Level 2: Several limitations of the experiment are evaluated and it is justified whether the student's conclusion is valid – however no attempt to link bounce height to a calculation of efficiency is made. (3-4 marks)

Level 1: Some limitations of the experiment are described and a comment about whether the conclusion is valid is made. (1-2 marks)

Indicative content

Making the conclusion

- A calculation of the efficiency at two different temperatures is made: e.g. at 60^0C the average bounce height is 43.5cm. This means the GPE after the bounce = mgh = 0.025 × 10 × 0.435 = 0.10875 J; GPE before the bounce = 0.025 × 10 × 1 = 0.25 J; so the efficiency is 0.10875 / 0.25 = 0.435 or 43.5%. A similar calculation of efficiency at a lower temperature shows a smaller efficiency.
- An alternative numerical treatment would be to realise that GPE = mgh so GPE before the bounce / GPE after the bounce = height before the bounce / height after the bounce. This means that the higher the bounce, the greater the efficiency
- The student's conclusion correctly describes the pattern of the data – the average bounce height increases as the temperature increases so the efficiency does increase with increasing temperature.

Quality of the data

- The repeat readings need to be averaged before any calculations and conclusions are made
- The repeat readings are quite different which suggests there is lots of random error – particularly at the low temperatures.
- One of the readings at 20^0C might be anomalous and would need to be re-checked.

Limitations of the procedure

- The ball's temperature might have decreased between it being in the water bath and being dropped …
- … this would have a greater effect at higher temperatures
- The ball might not have fallen and bounced vertically
- The ball might not be at the same temperature as the water (it doesn't conduct heat very well)
- It is difficult to judge when the ball has reached the maximum height
- There will be error due to not reading the ruler at the right angle (parallax error) as it would be impossible to move your eyes up and down so they are always level with the ball
- The metre ruler might not have been held vertically.