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Answers

Practice-for-exam questions

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The power behind the bike

1 **a** At 30 km h^{-1}, the power required is approximately 180 W.

b Energy transfer, *E*, = force × distance travelled in direction of the force = *F* × *d*

$$\text{power} = \frac{\text{energy transfer}}{\text{time taken}} = \frac{F \times d}{t} = F \times \frac{d}{t} = F \times v$$

c 30 km h^{-1} = $\frac{30\,000\ \text{m}}{3600\ \text{s}} = 8.33\ \text{ms}^{-1}$

d $F = \frac{\text{power}}{\text{velocity}} = \frac{180\ \text{W}}{8.33\ \text{ms}^{-1}} = 21.6\ \text{N} \approx 22\ \text{N}$

e Chris Froome has a mass of 66 kg and a power per unit mass of 6.1 W kg^{-1}

This gives a FTP of 66 kg × 6.1 W kg^{-1} = 403 W.

f From Figure 2, the component of weight down the hill = *mg* sin *α* where *α* is the angle of the hill from the horizontal. Therefore, the additional resistive force, F_A, on the bicycle climbing the hill:

$$F_A = (66 + 5)\ \text{kg} \times 9.8\ \text{N kg}^{-1} \times sin\ (\alpha)$$

Chris Froome still needs to expend 180 W to keep the bicycle travelling at 30 km h^{-1}. Therefore, there are 403 W – 180 W = 223 W available to climb the hill at 30 km h^{-1}.

Therefore, using: $\text{power} = F \times v$

$$\Longrightarrow 223\ \text{W} = \big((66 + 5)\ \text{kg} \times 9.8\ \text{N kg}^{-1} \times sin\ (\alpha)\big) \times 8.33\ \text{m s}^{-1}$$

$$\Rightarrow 696\ N \times sin\ (\alpha) = \frac{223\ W}{8.33\ ms^{-1}} \Longrightarrow Sin\ (\alpha) = \frac{223\ W}{8.33\ ms^{-1} \times 696\ N} = 0.0385$$

therefore $\alpha = sin^{-1}(0.0385) = 2.2°$

Perpetual motion

1 The generally accepted explanation is that radiation, which does not have to be visible light but can be IR or UV, falls on the vanes and heats them slightly. The black side will absorb the radiation a little more than the shiny or white side and so will be very slightly warmer.

Gas particles in the bulb will hit the vanes on both sides. If the temperature of both sides is the same then the gas particles will, on average, rebound at the same velocity and with the same momentum from each side. The change of momentum of the gas particles, hitting each side, will be the same and the forces on each side of a vane will therefore be equal and opposite so the vanes will not move.

However, when the temperature of the black side is slightly higher than the shiny or white side, the gas particles hitting the black side gain a little more energy than those hitting the shiny or white side and so rebound faster. Therefore, conservation of momentum requires that there is a resultant force on the black side of each vane causing the vanes to spin with the black side trailing.

A similar argument can be made using ideas of pressure, since because of a temperature difference, the gas on the black side will be at a very slightly higher pressure than on the shiny or white side, so there will be a resultant force on the black side.

In either case, energy is transferred by radiation to a thermal store in the vanes and mechanically to a kinetic store in the gas and the spinning vanes.

There is more explanation and further investigation at www.tinyurl.com/howcrookesradio

At a glance: on the surface

1 Paint has a low surface tension so it can spread easily over a large area. If the surface tension were greater, the paint would be much harder to spread.

2 **a** The surface tension acts at the edges of the plate. The perimeter of the plate has a length of 4 cm, or 0.04 m.

The surface tension of water is 0.07 N m^{-1}.

Hence, the force acting on the edge of the metal square is:

$0.07\ \text{N m}^{-1} \times 0.04\ \text{m} = 0.0028\ \text{N} = 2.8 \times 10^{-3}\ \text{N}$

b If a square wire were used, surface tension would act both on the inside and the outside of the square, so the force would be double that calculated above.

Domestic heat pumps

1 **a** 90% of 25 million homes in the UK have a gas boiler. This is about 22.5 million gas boilers (or 23 million, as given later in the article). If each produces, on average, 2 tonnes of CO_2 per year, this is 45 million tonnes of CO_2 per year. This is equivalent to the CO_2 absorbed by approximately 2 billion trees each year.

b Some of the factors to be considered are:

- desired temperature difference between inside and outside
- size and number of current radiators
- effectiveness of insulation and draught proofing
- whether there is or can be underfloor heating
- the expected CoP for the system

- how hot water is currently heated (does the house have a hot water tank or space for one?)

c The efficiency of a system depends on as small difference as possible between the heat source and the inside of the house. A ground-source heat pump with collectors too concentrated might cool the ground more quickly than it can be warmed from the surroundings and so will increase the temperature difference between the source and the inside of the house, decreasing efficiency.

Skillset: measuring the speed of sound

1 **a** You should count as many complete waves as possible. A possible calculation is that there are 5 complete waves in 1200 μs.

This gives $\frac{1200 \times 10^{-6}\text{ s}}{5} = 2.4 \times 10^{-4}$ s as the time period, *T*, for one wave.

$f = \frac{1}{T} = \frac{1}{2.4 \times 10^{-4}\text{ s}} = 4167\text{ Hz}$

b From equation 2 in the article:

$\lambda = v \times \frac{1}{f} \Longrightarrow \lambda_{best} = 355\text{ ms}^{-1} \times 2.4 \times 10^{-4}\text{s} = 0.0852\text{ m} = 8.52\text{ cm}$

$\lambda_{max} = 389\text{ ms}^{-1} \times 2.4 \times 10^{-4}\text{ s} = 0.0934\text{ m} = 9.34\text{ cm}$

$\lambda_{min} = 334\text{ ms}^{-1} \times 2.4 \times 10^{-4}\text{ s} = 0.0802\text{ m} = 8.02\text{ cm}$

Therefore, the spread of wavelengths is 9.34 cm – 8.02 cm = 1.32 cm and the range is ±0.66 cm.

The conclusion is that we can calculate the wavelength as (8.52 ± 0.66) cm.

Physics online: royal crystals

1 From the YouTube video:

$n = \frac{1}{\sin C} \Longrightarrow \sin c = \frac{1}{n} = \frac{1}{1.57} = 0.637 \Longrightarrow c = sin^{-1}(0.637) = 39.6°$

2 Red, blue and purple wavelengths will give the amethyst its purple colour and so the wavelengths that need to be absorbed are in the centre of the visible spectrum around green (specifically, around 545 nm).

3 If x is the fraction of gold in the wreath, then (1–x) is the fraction of silver.

Therefore $x \times 19\,300\text{ kg m}^{-3} + (1 - x) \times 10\,490\text{ kg m}^{-3} = 17\,560\text{ kg m}^{-3}$

$\Longrightarrow (19\,300\text{ kg m}^{-3} - 10\,490\text{ kg m}^{-3})x = 17\,560\text{ kg m}^{-3} - 10\,490\text{kg m}^{-3}$

$\Longrightarrow (8810\text{ kg m}^{-3})x = 7070\text{ kg m}^{-3} \Longrightarrow x = \frac{7070\text{ kg m}^{-3}}{8810\text{ kg m}^{-3}} = 0.802$

The wreath was about 0.8 (80%) gold and 20% silver.