**HWA CHONG INSTITUTION**
**JC2 Preliminary Examination**
**Higher 2**

| | | | |
|---|---|---|---|
| **CANDIDATE NAME** | | **CT GROUP** | 22S |
| **CENTRE NUMBER** | | **INDEX NUMBER** | |

# PHYSICS — 9749/02

**Paper 2 Structured Questions**

**13 September 2023**

**2 hours**

Candidates answer on the Question Paper.

No Additional Materials are required.

## READ THESE INSTRUCTIONS FIRST

Write your Centre Number, index number and name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

The number of marks is given in brackets [ ] at the end of each question or part question.
You are reminded of the need for good English and clear presentation in your answers.

| For Examiner's Use | | |
|---|---|---|
| Paper 2 | | |
| 1 | | 11 |
| 2 | | 9 |
| 3 | | 7 |
| 4 | | 10 |
| 5 | | 10 |
| 6 | | 12 |
| 7 | | 21 |
| Deductions | | |
| Total | | 80 |

| Data | Formulae | |
|---|---|---|
| speed of light in free space, $c = 3.00 \times 10^{8}$ m s$^{-1}$ | uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$ <br> $v^2 = u^2 + 2as$ |
| permeability of free space, $\mu_o = 4\pi \times 10^{-7}$ H m$^{-1}$ | work done on / by a gas | $W = p\,\Delta V$ |
| permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-12}$ F m$^{-1}$ <br> $\approx (1/(36\pi)) \times 10^{-9}$ F m$^{-1}$ | hydrostatic pressure | $p = \rho gh$ |
| | gravitational potential | $\phi = -\frac{Gm}{r}$ |
| elementary charge, $e = 1.60 \times 10^{-19}$ C | temperature | $T$/K = $T$/ °C + 273.15 |
| | pressure of an ideal gas | $P = \frac{1}{3}\frac{Nm}{V} < c^2 >$ |
| the Planck constant, $h = 6.63 \times 10^{-34}$ J s | mean kinetic energy of a molecule of an ideal gas | $E = \frac{3}{2}kT$ |
| unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg | displacement of particle in s.h.m. | $x = x_o \sin \omega t$ |
| rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg | velocity of particle in s.h.m. | $v = v_o \cos \omega t$ <br> $= \pm\,\omega\sqrt{(x_o^{\,2} - x^2)}$ |
| rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg | electric current | $I = Anvq$ |
| molar gas constant, $R = 8.31$ J K$^{-1}$ mol$^{-1}$ | resistors in series | $R = R_1 + R_2 + \ldots$ |
| | resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| the Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ | electric potential | $V = \frac{Q}{4\pi\varepsilon_o r}$ |
| the Boltzmann constant, $k = 1.38 \times 10^{-23}$ J K$^{-1}$ | alternating current / voltage | $x = x_o \sin \omega t$ |
| gravitational constant, $G = 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$ | magnetic flux density due to a long straight wire | $B = \frac{\mu_o I}{2\pi d}$ |
| acceleration of free fall, $g = 9.81$ m s$^{-2}$ | magnetic flux density due to a flat circular coil | $B = \frac{\mu_o NI}{2r}$ |
| | magnetic flux density due to a long solenoid | $B = \mu_o nI$ |
| | radioactive decay | $x = x_o \exp(-\lambda t)$ |
| | decay constant | $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$ |

**1** **(a)** A wooden block placed on a weighing scale on a table registers 1.6 kg.

The same block and the weighing scale are now placed on a rough slope as shown in Fig. 1.1.

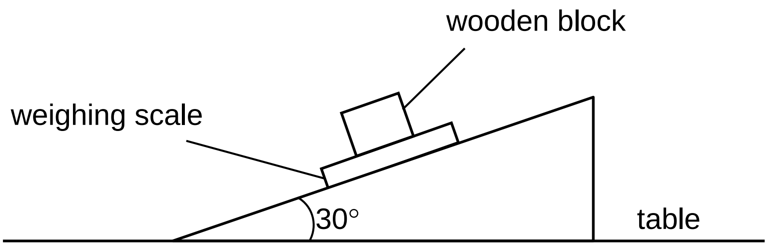


**Fig. 1.1**

The slope is at an angle of 30° to the horizontal.

Determine the new reading on the weighing scale. Show your working clearly.

new reading on the weighing scale = ………………….. kg [3]

**(b)** The same block is now suspended from the ceiling by a cord of length 1.3 m.

A tennis ball of mass 58 g is shot from a launcher and strikes the block horizontally.

The ball is in contact with the block for a time of 0.20 s during which it reverses its direction and moves off with a speed of 19 m $s^{-1}$. After the collision, the block swings to a maximum angle of 37° from its initial vertical position.

Assume that during the collision, vertical motions are negligible.

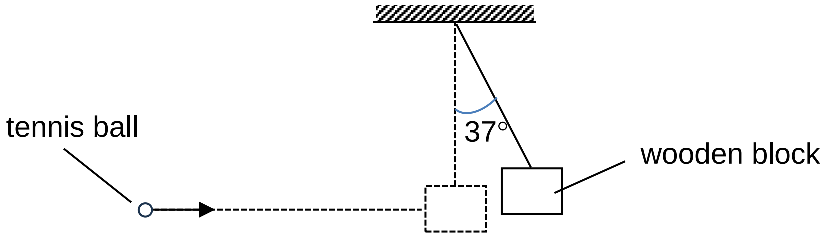


**Fig. 1.2**

**(i)** Show that the speed of the block immediately after the collision is 2.3 m $s^{-1}$.

[2]

**(ii)** Calculate the average force *F* between the ball and the block during the collision.

*F* = ………………….. N [2]

**(iii)** Determine the horizontal speed of the ball before the collision.

initial speed of the ball = ………………….. m $s^{-1}$ [2]

**(c)** Using your answers in **(b)**, deduce whether the collision is elastic.

……………………………………………………………………………………………………

…………………………………………………………………………………………………….[2]

[Total: 11]

**2** **(a)** State Newton's Law of Gravitation.

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…………………………………………………………………………………………………….…. [1]

**(b)** A geostationary satellite is placed in orbit around the Earth.

**(i)** Explain why the satellite must be above the equator.

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…………………………………………………………………………………………………. [2]

**(ii)** Given that the mass of the Earth is $6.0 \times 10^{24}$ kg and the radius of the Earth is $6.4 \times 10^{6}$ m,

**1.** show that the altitude of the satellite above the surface of the Earth is $3.6 \times 10^{7}$ m,

[4]

**2.** calculate the linear speed of the satellite.

linear speed = …………………….. m $s^{-1}$ [2]

[Total: 9]

3 A string, tied to a sinusoidal oscillator at P and running over a support at Q, is stretched by a block of mass *m* as shown in Fig. 3.1. The amplitude of the motion at P is small enough for that point to be considered a node. A node also exists at Q.

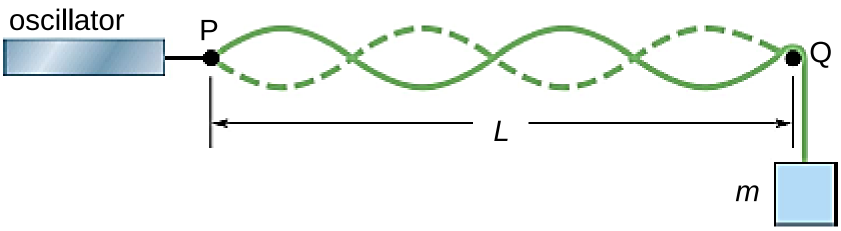


**Fig. 3.1**

**(a)** Explain how a stationary wave is formed along the string.

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**(b)** Explain why the incident wave must undergo a phase change of 180° at point Q.

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**(c)** The frequency of the oscillator is set at 120 Hz. A stationary wave is formed when the length *L* is 1.20 m. The length is slowly increased and the stationary wave disappears. The stationary wave is again formed when *L* is increased by 0.30 m.

**(i)** Calculate the velocity of the wave in the string.

wave velocity = ......................... m $s^{-1}$ [2]

**(ii)** Given that the amplitude of the antinodes is 0.80 cm, calculate the maximum *vertical* velocity for a point on the string.

maximum vertical velocity = ......................... m $s^{-1}$ [2]

[Total: 7]

**4** **(a)** Define electric potential at a point.

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**(b)** An isolated nucleus in a vacuum produces electric potential *V* at a distance *r* from its centre. Fig. 4.1 shows the variation with *r* of *V*.

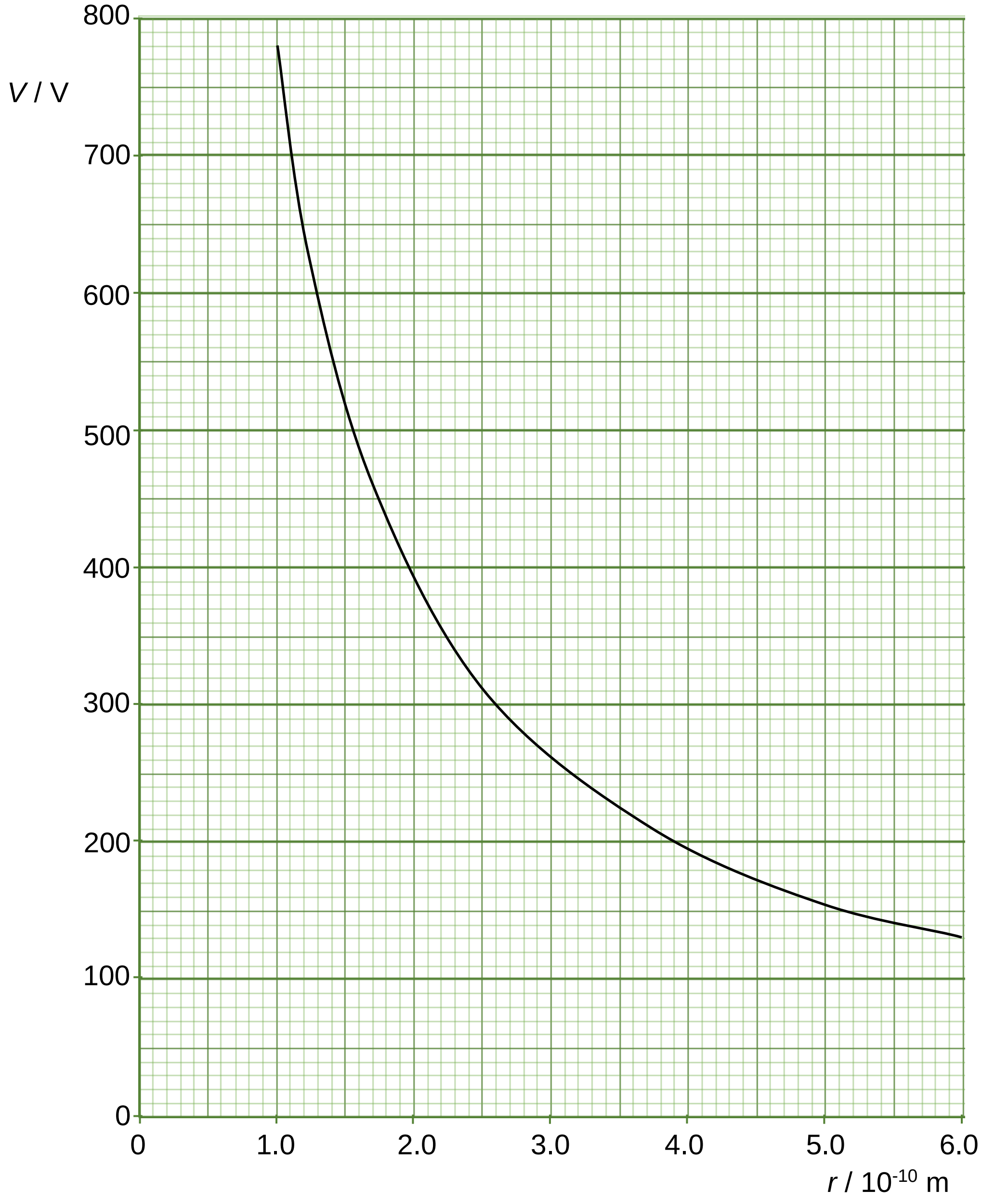


**Fig. 4.1**

**(i)** Use data from Fig. 4.1 to show that there are 54 protons in the nucleus.

[3]

**(ii)** A single proton is placed at a distance of $2.0 \times 10^{-8}$ m from the centre of the nucleus.

Suggest why it may be assumed that the proton and the nucleus behave as point charges.

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…………………………………………………………………………………………………….. [1]

**(iii)** **1.** Explain how the magnitude of the electric field strength at a distance *r* between $1.0 \times 10^{-10}$ m and $6.0 \times 10^{-10}$ m from the centre of the nucleus can be obtained from the curve in Fig. 4.1.

……………………………………………………………………………………………..

……………………………………………………………………………………………….. [1]

**2.** Hence or otherwise, determine the electric force on a proton that is at $2.6 \times 10^{-10}$ m from the centre of the nucleus.

magnitude of the force = …………………………. N

direction of the force = ……………………………………………..

[4]

[Total: 10]

**5** **(a)** Distinguish between electromotive force and potential difference.

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…………………………………………………………………………………………………….. [2]

**(b)** The circuit in Fig 5.1 consists of one battery with an e.m.f. of 12.0 V connected to a resistance wire of uniform resistivity and uniform cross-sectional area.

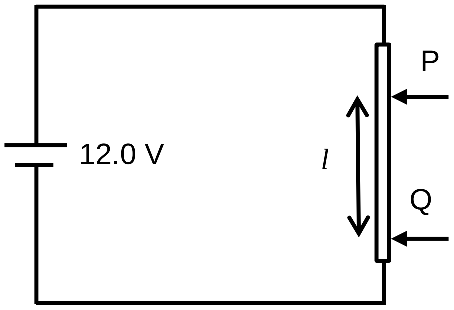


**Fig 5.1**

Explain why the potential difference between two points P and Q on the resistance wire is proportional to the distance between P and Q.

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…………………………………………………………………………………………………….. [2]

**(c)**

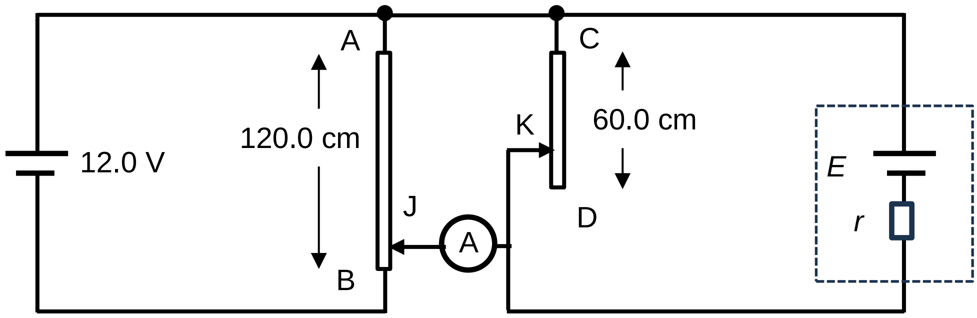


**Fig 5.2**

Fig 5.2 shows a circuit consisting of two parts.

The part on the left consists of a battery having an e.m.f. of 12.0 V, with negligible internal resistance, connected to a uniform resistance wire of length 120.0 cm.

The part on the right consists of a battery having an unknown e.m.f. *E,* with internal resistance *r*, connected to another uniform resistance wire of different resistivity and cross-sectional area, 60.0 cm in length.

The two jockeys J and K, which are connected to each other through an ideal ammeter, are free to move along the resistance wires AB and CD respectively.

The ammeter shows zero reading when the distance AJ is 54.0 cm and CK is 60.0 cm, and also when AJ is 45.0 cm and CK is 20.0 cm.

**(i)** Show that the potential difference (p.d.) across CK is 5.4 V when the length CK is 60.0 cm.

[2]

**(ii)** Given that the p.d. across CK is 4.5 V when the length CK is 20.0 cm, and the resistance of the resistance wire CD is 4.5 Ω.

Determine $E$ and $r$.

$E$ = …………………… V

$r$ = …………………… Ω

[4]

[Total: 10]

**6** **(a)** In the $\alpha$-particle scattering experiment, $\alpha$-particles travelling in a vacuum are incident on a gold foil. The $\alpha$-particles are shot at the gold foil one at a time.

On Fig 6.1, complete the path of each $\alpha$-particle as it passes the gold nucleus.

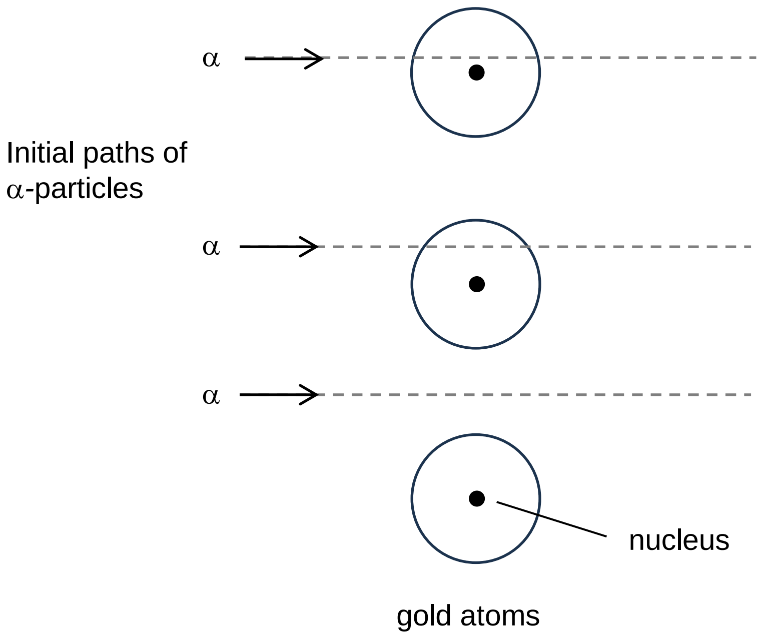


**Fig. 6.1**

[3]

**(b)** Describe and explain how the $\alpha$-particle scattering experiment which you have illustrated in part **(a)** gives evidence for the existence and small size of the nucleus.

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**(c)** The structure of the nucleus was clarified further by an experiment in which $\alpha$-particles were fired at a piece of beryllium. A nuclear reaction took place in the beryllium and the reaction is now known to be

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{1}_{0}n + ^{12}_{6}C$$

**(i)** What information does the symbol, $^{4}_{2}He$ give about the $\alpha$-particle?

.................................................................................................................. [1]

**(ii)** Data for the particles in the reaction in part **(c)** are given as follows.

| particle | mass / u |
|---|---|
| $^{4}_{2}He$ | 4.00260 |
| $^{9}_{4}Be$ | 9.01212 |
| $^{1}_{0}n$ | 1.00867 |
| $^{12}_{6}C$ | 12.00000 |

Calculate the energy associated with the change in mass in the reaction.

energy = .............................. J [3]

**(iii)** Explain whether the products in the reaction have a higher or lower total binding energy than the reactants.

..................................................................................................................

.................................................................................................................. [1]

[Total :12]

**7** Read the passage and answer the questions that follow.

In World War II, Nazi Germany fought a bombing campaign against the British. The Germans developed a radio navigation system called *X-Gerät* ("X-Apparatus") to help their bombers find their targets more accurately. In turn, the British developed countermeasures, aiming to jam the German signals or lead the bombers off-course. This period of the war came to be known as the "Battle of the Beams."

*X-Gerät* consists of radio arrays called *Knickebein* ("crooked leg"). Each *Knickebein* array had eight radio antennae, which behave like point sources of radio waves, suspended 6.0 m apart, transmitting radio waves at a frequency of 30.0 MHz. The waves from these antennae superpose to produce a single beam of radio waves, which spreads out with an angle $\alpha$ as shown in Fig. 7.1. This guides an aircraft equipped with a radio receiver, to fly in a straight line towards their target.

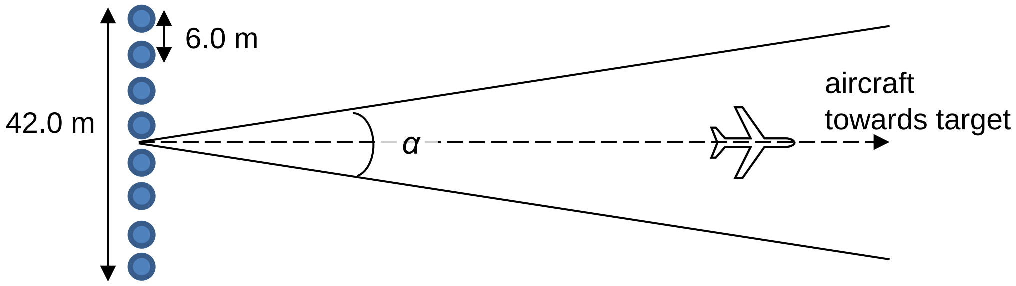


**Fig. 7.1**

The accuracy of this method of navigation is limited by the width of the beam, especially at long ranges. The narrower the beam, the more accurate the guidance system – but it is difficult to make the angle $\alpha$ small enough to be practical at the long ranges required. However, the German engineers managed to come up with a solution that significantly reduced the *Knickebein* beam's actual angular width.

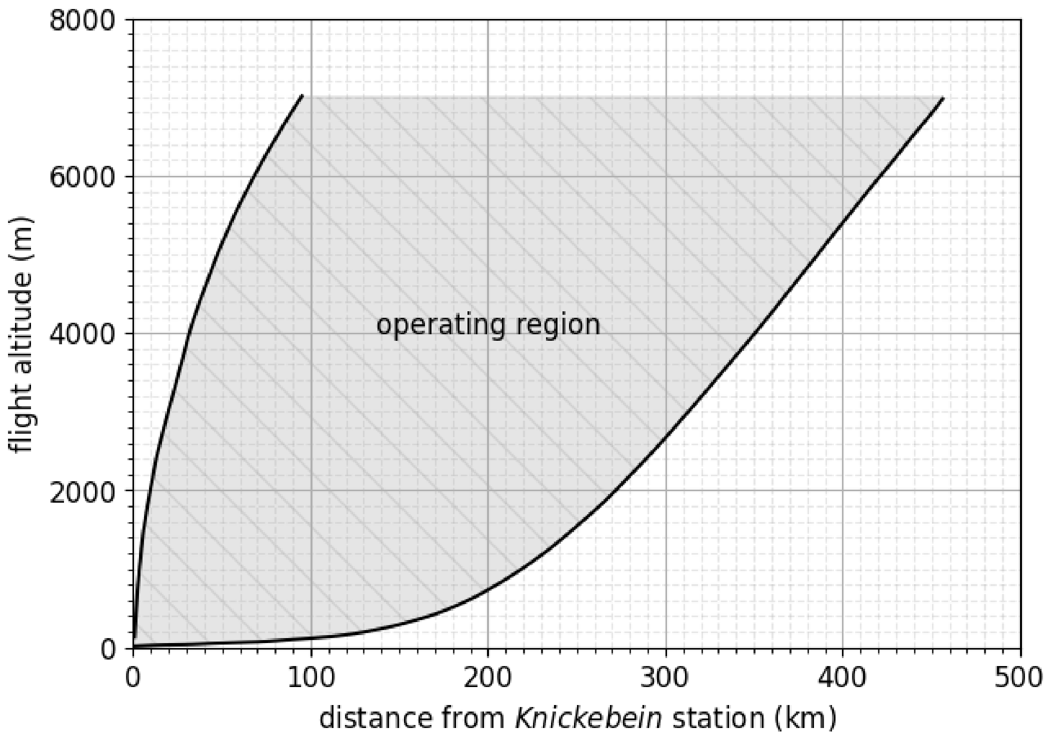


**Fig. 7.2**

Whether the signal can be detected by the aircraft depends on its altitude and distance from the *Knickebein* station. Fig. 7.2 is a graph of flight altitude against distance from the *Knickebein* station. The shaded “operating region” between the two curves represents the region where the intensity of the radio waves is large enough for the aircraft to detect it.

In the *X-Gerät* system, the bomber flies along one *Knickebein* beam (the “guide beam”) in a straight line towards its target at a constant speed and altitude. As the bomber approaches the target, it flies through two more *Knickebein* beams (*Oder* and *Elbe*), which are perpendicular to its path, as shown in Fig. 7.3. These beams are used to control when the bomb should be released.

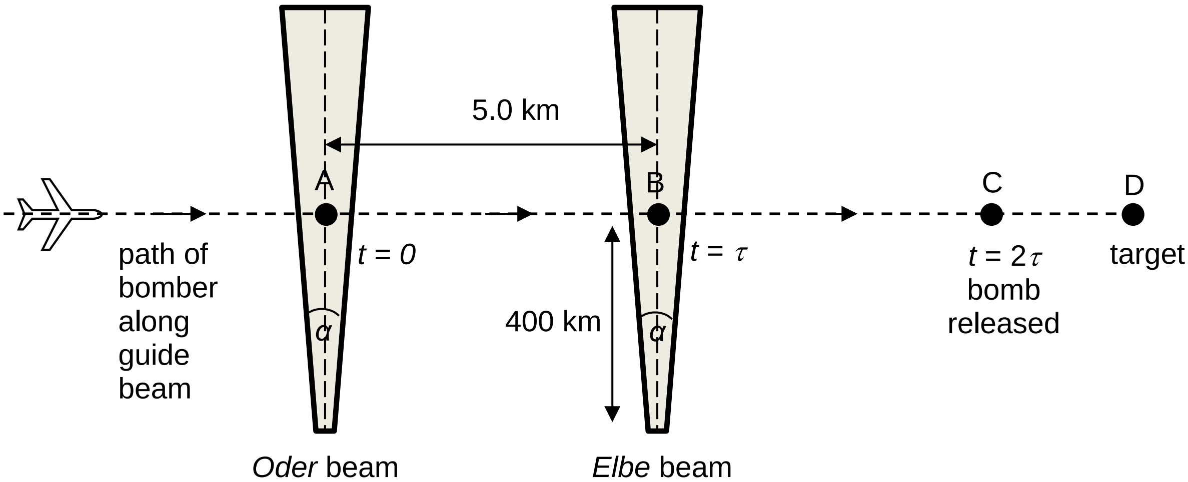


**Fig. 7.3**

When the bomber detects the *Oder* beam (at point A), a stopwatch is started. After travelling 5.0 km, the bomber detects the *Elbe* beam (at point B), and the stopwatch reading $\tau$ is noted. At point C, the stopwatch reading is $2\tau$, and the bomb is released, which falls and lands on the target at D. The *Oder* and *Elbe* beams originate from *Knickebein* stations in occupied Europe, about 400 km away, and thus have non-negligible widths. This contributes some uncertainty that may cause the bomb to miss.

**(a)** **(i)** The *Knickebein* array of radio antennae results in interference of radio wave, similar to visible light that has been passed through a diffraction grating.

Using the data from Fig. 7.1, show that the *Knickebein* array produces only a single beam.

[2]

**(ii)** This beam of radio wave spreads out as it travels, like a wave passing through a single slit of the same width as the entire array of radio antennae.

For the arrangement of sources in Fig. 7.1, calculate $\alpha$, the angular width of the beam.

$\alpha$ = ................................° [3]

**(b)** **(i)** The bomber is flying at the minimum altitude for it to have a detectable signal 400 km from the *Knickebein* station.

State this altitude.

altitude = ................................ m [1]

**(ii)** The time shown on the stopwatch when the bomber crosses the Elbe beam is $\tau$ = 51.4 s.

Show that the speed of the bomber is 97.3 m s$^{-1}$.

[1]

**(iii)** Determine CD in Fig. 7.3, the horizontal distance from the release point to the target.

CD = ................................ m [3]

**(iv)** Now, the bomber is flying at a greater speed than your answer to **(b)(ii)**, but the same altitude as in **(b)(i)**; the positions of the *Elbe* and *Oder* beams (A and B respectively) are unchanged.

Explain whether the bomb released at point C will still hit the target.

…………………………………………………………………………………………………………

…………………………………………………………………………………………………………

………………………………………………………………………………………………… [2]

**(v)** The German engineers managed to reduce the angular width $\alpha$ of the beam to 0.3° instead of the value you found in **(a)(ii)**.

Determine the uncertainty in the position of point A due to the angular width of the *Oder* beam.

uncertainty = …………………………… m [2]

**(c)** The German bomber used with the *Knickebein* was the Heinkel He 111H, which had the technical specifications in Table 7.1.

| | |
|---|---|
| Crew | 5 |
| Propulsion for propellers | 2 piston engines |
| Power of one piston engine | 990 kW |
| Maximum speed | 435 km/h |
| Service ceiling | 6700 m |
| Range | 1950 km |
| Empty weight | 8680 kg |
| Maximum take-off weight | 14000 kg |

**Table 7.1**

Forces acting on a Heinkel He 111H flying at constant speed and altitude are shown in Fig. 7.4.

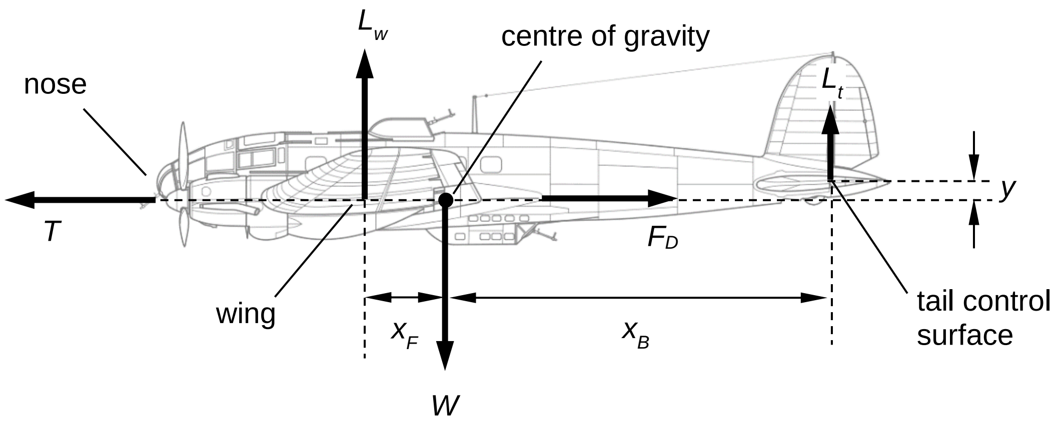


**Fig. 7.4**

$T$ is the thrust from the propellers, $L_w$ is the lift from the wings, $L_t$ is the lift from the tail control surfaces, $W$ is the weight of the aircraft, and $F_D$ is the drag force.

The centre of gravity is a distance $x_F$ away from the centre of lift of the wings and a distance $x_B$ from the tail control surfaces.

The centre of lift of the tail control surfaces is at a perpendicular distance $y$ above the centre of gravity.

**(i)** Take moments about the centre of gravity, to show that, when the aircraft is level and flying at constant speed and altitude,

$$L_t = \frac{Wx_F}{x_F + x_B}$$

[2]

**(ii)** Explain clearly why the drag force $F_D$ does not appear in the relationship in **(c)(i).**

..........................................................................................................................

.......................................................................................................................... [1]

**(iii)** Using data from Table 7.1, determine the magnitude of the drag force $F_D$ on the bomber when it is travelling at a constant speed of 200 km $h^{-1}$.

$F_D$ = ................................ N [4]

[Total: 21]

**End of paper**

Copyright Acknowledgements:

Frank Dorenberg. *"Knickebein" beacon*, Non Stop Systems.
Url: https://www.nonstopsystems.com/radio/hellschreiber-modes-other-hell-RadNav-knickebein.htm

Drawing Database. *Heinkel He 111 Blueprint.* Url: https://drawingdatabase.com/heinkel-he-111/ (Fig 7.4)

Flugzeug info.net. *Heinkel He 111.* Url: http://www.flugzeuginfo.net/acdata_php/acdata_he111_en.php (Table 7.1)