InkPhysics

ANSWER BOOK

Newton's law of gravitation

Gravitational fields · Year 13

AQA 3.7.2.1, 3.7.2.2 · CIE 13.1.1, 13.2.1, 13.2.2, 13.3.1, 13.3.2
OCR A 5.4.1(b), 5.4.1(d), 5.4.2(a), 5.4.2(b), 5.4.2(c)

19 questions · 53 marks

NAVY EDITION

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SECTION A · Warm-up

A1 The force is attractive and proportional to the product of the masses (1); and inversely proportional to the square of their separation, $F = GMm/r^2$ (1). [2]

A2 $F = GMm/r^2 = (6.67 \times 10^{-11} \times 5.0 \times 5.0)/2.0^2$ (1)
$F = 4.17 \times 10^{-10}$ N (1) [2]

A3 Gravitational force per unit mass on a small test mass at the point (1); $g = F/m$ (1). [2]

A4 590 N: by Newton's third law the two forces are equal in magnitude (and opposite in direction) (1). The Earth's mass is enormous, so its acceleration $a = F/M$ is far too small to notice (1). [2]

A5 g follows an inverse-square law, so trebling the distance from the centre divides g by $3^2 = 9$ (1)
$g = 9.8/9 = 1.1$ N kg^{-1} (1) [2]

A6 A mass whose size is negligible compared with the separation involved, so that it can be treated as being at a single point (1). A (uniform) sphere behaves, from outside, as if all its mass were concentrated at its centre, so the law applies with r measured from the centre (1). [2]

SECTION B · Standard

B1 $F = GMm/r^2 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24} \times 7.3 \times 10^{22})/(3.8 \times 10^8)^2$ (1)
$F = 2.02 \times 10^{20}$ N (1) [2]

B2 $g = GM/r^2 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24})/(6.4 \times 10^6)^2$ (1)
$g = 9.77$ N kg^{-1} (1) [2]

B3 $g = GM/r^2 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24})/(1.28 \times 10^7)^2$ (1)
$g = 2.44$ N kg^{-1} (1)
This is one quarter of the surface value: the distance has doubled, so g falls by a factor of 4 (inverse-square law) (1). [3]

B4 $g = GM/r^2 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24})/(7.0 \times 10^6)^2 = 8.17$ N kg^{-1} (2)
$F = mg = 500 \times 8.17 = 4084$ N $\approx 4.1 \times 10^3$ N (1) [3]

B5 Conversions: $m = 0.074$ kg, $r = 0.060$ m (1) [3]
$F = Gm^2/r^2 = (6.67 \times 10^{-11} \times 0.074^2)/0.060^2 = 1.0 \times 10^{-10}$ N (1)
This is negligible compared with the other forces on a ball, such as its weight (about 0.7 N) or friction from the table (1).

B6 $F = GMm/r^2 = (6.67 \times 10^{-11} \times 2.0 \times 10^{30} \times 6.4 \times 10^{23})/(2.3 \times 10^{11})^2$ (1) [4]
$F = 1.61 \times 10^{21}$ N (1)
$a = F/m = 1.61 \times 10^{21}/(6.4 \times 10^{23})$ (1)
$a = 2.5 \times 10^{-3}$ m s^{-2} (1)

B7 $r = \sqrt{(GM/g)}$ (1) [3]
$r = \sqrt{((6.67 \times 10^{-11} \times 6.4 \times 10^{23})/1.0)}$ (1)
$r = 6.5 \times 10^6$ m (1)

SECTION C · Stretch

C1 $g = GM/r^2$ (1) [3]
$g = (6.67 \times 10^{-11} \times 6.4 \times 10^{23})/(3.4 \times 10^6)^2$ (1)
$g = 3.69$ N kg$^{-1} \approx 3.7$ N kg^{-1} (1)

C2 $M = gr^2/G$ (1) [3]
$M = (9.81 \times (6.4 \times 10^6)^2)/(6.67 \times 10^{-11})$ (1)
$M = 6.02 \times 10^{24}$ kg (1)

C3 The field lines spread out over a larger area as distance increases, so the field becomes weaker (1). From $g = GM/r^2$, g follows an inverse-square law with distance from the centre (1); for example, doubling r reduces g to one quarter of its value (1). [3]

C4 Use of $g = GM/r^2$ for each planet (1) [4]
$g_K = (6.67 \times 10^{-11} \times 3.0 \times 10^{25})/(1.6 \times 10^7)^2 = 7.8$ N kg^{-1} (1)
$g_L = (6.67 \times 10^{-11} \times 8.9 \times 10^{24})/(7.7 \times 10^6)^2 = 10.0$ N kg^{-1} (1)
The claim is not correct: only L exceeds 9.8 N kg^{-1}; K's larger mass is outweighed by its larger radius (1).

C5 Sensible estimate of the masses, for example 70 kg each (1) [3]
$F = Gm_1m_2/r^2 = (6.67 \times 10^{-11} \times 70 \times 70)/1.0^2 \approx 3.3 \times 10^{-7}$ N (1)
This is of order 10^{-7} N against a weight of about 700 N: some nine orders of magnitude smaller, which is why we never notice the attraction (1).

C6 $r = 6.4 \times 10^6 + 4.2 \times 10^5 = 6.82 \times 10^6$ m, measured from the planet's centre (1) [5]
$g = GM/r^2 = (6.67 \times 10^{-11} \times 6.0 \times 10^{24})/(6.82 \times 10^6)^2$ (1)
$g = 8.60$ N kg^{-1} ≈ 8.6 N kg^{-1} (1)
The laboratory and the crew are both in free fall, accelerating towards the planet at the same rate (1); there is therefore no contact (support) force between the crew and the laboratory, so the crew appear weightless (1).