OCR A A Level Physics: Moments and equilibrium solutions

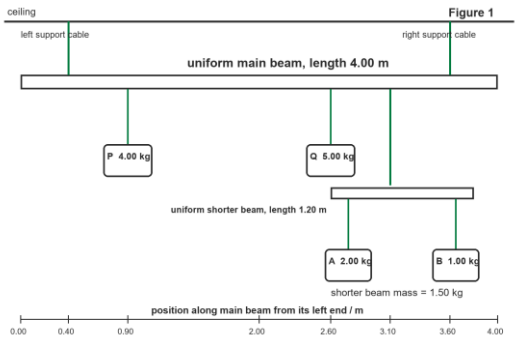
Matching solutions and teaching prompts for the class review

Specification points covered

- 3.2.1(c) Understand weight of an object, W = mg.
- 3.2.1(d) Define and identify tension.
- 3.2.3(a) Define moment of a force; moment = F × x.
- 3.2.3(c) State and apply the principle of moments.
- 3.2.3(d) Define the centre of mass and centre of gravity.
- 3.2.3(e) Describe equilibrium of an object under the action of forces and torques.

Teaching focus

Insist on perpendicular distance to a line of action. Keep translational equilibrium (resultant force = 0) distinct from rotational equilibrium (resultant moment = 0), and model tension as a pulling force along a taut cord or cable.



1. Define the moment of a force about a point. [1 mark]

Answer / mark points: The moment of a force about a point is its turning effect about that point. Its magnitude is force multiplied by the perpendicular distance from the point to the force's line of action: M = F × d, where d is the perpendicular distance.
Teacher prompt / common error: Require perpendicular distance to the line of action, not simply the distance to the point where the force is applied.

2. Define tension. State the direction in which a tension force acts. [1 mark]

Answer / mark points: Tension is the pulling force transmitted by a taut string, cord or cable. It acts along the string, cord or cable and pulls on the attached object.
Teacher prompt / common error: Tension is a pulling force. A string or cable cannot push, and the force acts along it.

3. The complete display is in equilibrium. State the two conditions that must be satisfied for equilibrium. [2 marks]

Answer / mark points: The resultant force is zero, and the resultant moment (or torque) about any point is zero.
Teacher prompt / common error: Use 'resultant force is zero' and 'resultant moment is zero'. Equilibrium does not mean that no forces act.

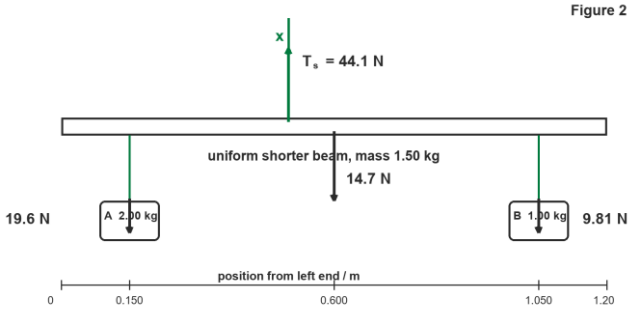
1. Definitions and equilibrium conditions continued

4. State the principle of moments using precise wording. [2 marks]

Answer / mark points: For an object in equilibrium, the sum of the clockwise moments about a point equals the sum of the anticlockwise moments about the same point.
Teacher prompt / common error: Both sets of moments must be taken about the same point, and the statement applies when the object is in equilibrium.

2. The shorter hanging beam

Figure 2



5. Treat the shorter beam and its two hanging objects as one system. On Figure 2 draw and label the four external forces acting on this system. [2 marks]

Answer / mark points: The four external forces are: T_s vertically upwards at the supporting cord; the weight of A vertically downwards at 0.150 m; the weight of the uniform shorter beam vertically downwards at its centre, 0.600 m; and the weight of B vertically downwards at 1.050 m.
Teacher prompt / common error: The system boundary includes both objects and the shorter beam. The downward forces are their weights; the upward external force is T_s.

6. Calculate the tension T_s in the cord supporting the shorter beam system. [2 marks]

Answer / mark points: T_s = total weight = (2.00 + 1.50 + 1.00) × 9.81 = 44.145 N = 44.1 N (3 s.f.).
Teacher prompt / common error: The shorter system has no vertical acceleration, so the upward tension equals the total downward weight.

7. Take moments about the left end of the shorter beam. Calculate the attachment position x that keeps the shorter beam horizontal. [3 marks]

Answer / mark points: Taking moments about the left end: 44.145x = (19.62 × 0.150) + (14.715 × 0.600) + (9.81 × 1.050). Therefore x = 22.0725 / 44.145 = 0.500 m from the left end.
Teacher prompt / common error: Every distance is measured to a vertical line of action. The weight of a uniform beam acts at its centre.

2. The shorter hanging beam continued

8. Explain why the cord exerts a downward force of the same magnitude on the main beam. [2 marks]

Answer / mark points: A cord can only pull, so it pulls upwards on the shorter beam system and downwards on the main beam. Because the cord is light and stationary, the tension has the same magnitude throughout it: 44.1 N.
Teacher prompt / common error: Avoid describing the two forces as acting on the same object. The cord pulls on two different objects in opposite directions.

9. Object B is moved 0.200 m to the left while the supporting cord remains at its original position. State the direction in which the shorter beam initially rotates and explain your answer. [2 marks]

Answer / mark points: The shorter beam initially rotates anticlockwise, so its left end moves down. Moving B left reduces its clockwise moment while the anticlockwise moments are unchanged, so there is a resultant anticlockwise moment.
Teacher prompt / common error: Moving B left reduces its clockwise moment. Encourage pupils to name which total moment is now larger before naming the rotation.

10. Calculate the new attachment position of the supporting cord that restores equilibrium after object B is moved. [2 marks]

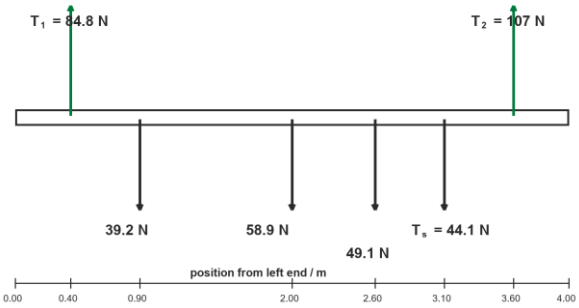
Answer / mark points: The new position of B is 0.850 m. T_s x = (19.62 × 0.150) + (14.715 × 0.600) + (9.81 × 0.850), so x = 0.456 m from the left end (3 s.f.). The cord must move about 0.044 m to the left.
Teacher prompt / common error: The total weight and T_s are unchanged. The new support position is the centre of mass of the complete shorter-beam system.

Key result

Original attachment position: 0.500 m from the left end. After B moves left: 0.456 m from the left end.

3. Support tensions in the main beam

Figure 3



11. Calculate the weights of the uniform main beam, object P and object Q. State the position at which the weight of the uniform main beam acts. [2 marks]

Answer / mark points: Main beam: W = 6.00 × 9.81 = 58.9 N. Object P: W = 4.00 × 9.81 = 39.2 N. Object Q: W = 5.00 × 9.81 = 49.1 N. The weight of the uniform main beam acts at its centre, 2.00 m from the left end.
Teacher prompt / common error: All three answers are weights in newtons. The main beam is uniform, so its centre of gravity is at the geometric centre.

12. Explain why taking moments about the left support removes T_1 from the moment equation. [1 mark]

Answer / mark points: The line of action of T_1 passes through the chosen pivot, so its perpendicular distance from the pivot is zero and its moment is zero.
Teacher prompt / common error: A force has zero moment about any point on its line of action.

13. Use the principle of moments about the left support to calculate the tension T_2 in the right support cable. [3 marks]

Answer / mark points: Taking moments about the left support: $T_2(3.60 - 0.40) = 39.24(0.90 - 0.40) + 58.86(2.00 - 0.40) + 49.05(2.60 - 0.40) + 44.145(3.10 - 0.40)$. Therefore $3.20T_2 = 340.8975$ and $T_2 = 106.5$ N = 107 N (3 s.f.).
Teacher prompt / common error: Using a support as the pivot removes one unknown. Check that distances are measured from 0.40 m, not from the left end of the beam.

14. Use vertical force equilibrium to calculate the tension T_1 in the left support cable. [2 marks]

Answer / mark points: $T_1 + T_2 = 39.24 + 58.86 + 49.05 + 44.145 = 191.295$ N. Therefore $T_1 = 191.295 - 106.531 = 84.8$ N (3 s.f.).
Teacher prompt / common error: After finding T_2, use resultant vertical force = 0. Do not assume the support tensions are equal.

4. Explaining and changing equilibrium

15. The main beam is horizontal and in equilibrium, but T_1 and T_2 are not equal. Explain why this is possible. [2 marks]

Answer / mark points: Equilibrium requires the total upward force to equal the total downward force and the moments to balance. It does not require individual support forces to be equal. The loads are not distributed symmetrically, so the right support provides the larger tension.
Teacher prompt / common error: Balanced forces concern totals; balanced moments depend on both force and perpendicular distance.

16. A pupil states, 'The display is in equilibrium, so no forces act on it.' Explain why this statement is incorrect. [2 marks]

Answer / mark points: Several non-zero forces act on the display. In equilibrium their vector sum is zero and their moments cancel, so there is no linear or angular acceleration.
Teacher prompt / common error: A static display has forces that balance. More generally, equilibrium allows constant velocity as well as rest.

17. Object Q is moved from 2.60 m to 1.60 m from the left end of the main beam. Without calculation, state how T_1 and T_2 change. Explain your reasoning. [3 marks]

Answer / mark points: T_2 decreases and T_1 increases. Moving Q left reduces the clockwise moment of the downward loads about the left support, so a smaller T_2 is needed. The total weight is unchanged, so the reduction in T_2 is balanced by an increase in T_1.
Teacher prompt / common error: The total upward support force stays the same because the total weight stays the same. Only its distribution between the supports changes.

18. Object Q is returned to its original position. An extra object of mass 3.00 kg is hung 3.80 m from the left end. The maximum safe tension in the right support cable is 120 N. Determine whether the cable remains safe. [4 marks]

Answer / mark points: The extra weight is $3.00 \times 9.81 = 29.43$ N. Taking moments about the left support: $T_2(3.20) = 340.8975 + 29.43(3.80 - 0.40) = 440.9595$ N m. Therefore $T_2 = 137.8$ N. This exceeds 120 N, so the right support cable is not safe.
Teacher prompt / common error: For full credit expect the added weight, the new moment equation, the new right-hand tension, and comparison with the stated limit.

Closing review

Equilibrium can involve many non-zero forces. The vector sum of the forces is zero and the total moment about any point is zero. Support forces need not be equal unless the loading is symmetric.