4.4 Connected particles and pulleys

Name: _____ Class: _____ Date: _____ **Total: 25 marks**

KEY WORDS tension • pulley

Connected particles and pulleys

Objective

Write equations of motion for each of two connected particles, find the acceleration and tension, the force on the pulley (2T), and follow the motion through phase changes (objectives 4.2).

1 Key knowledge and worked examples

The pattern. Light inextensible string over a light smooth pulley: same tension both sides, same speed magnitude. One equation per body in ITS direction of acceleration; add to eliminate T. The string exerts $2T$ on the pulley along the bisector. When a body lands or the string goes slack, a NEW phase starts with different forces – re-derive, do not reuse.

Worked example – the full pulley story (WME01 June 2025 Q8). P (mass kM) and Q (mass $3M$) over a fixed pulley accelerate at $\frac{g}{5}$: $T - kMg = \frac{kMg}{5}$ and $3Mg - T = \frac{3Mg}{5}$ give $k = 2$. With $M = 0.5$ kg, $T = 11.76$ N and the string pulls the pulley down with $2T = 23.5$ N. Q lands after 2.5 m at speed $\sqrt{g} = 3.13$; P coasts up decelerating at g for 0.32 s after the 1.60 s descent – total time to rest 1.9 s.

2 Practice

2.1 Masses of 3 kg and 5 kg hang over a light smooth pulley. Find the acceleration and the tension while they move. [4]

2.2 A 2 kg block on a smooth horizontal table is connected by a light inextensible string, passing over a light smooth pulley at the table edge, to a 3 kg hanging mass. Find the acceleration and the tension. [4]

2.3 For question 2.1, state the magnitude of the force exerted on the pulley by the string. [3]

2.4 After the system in 2.2 has been moving for a while, the hanging mass reaches the floor and the string goes slack. Describe the subsequent motion of the block on the table and the acceleration it experiences. [3]

3 Exam-style questions

3.1 *(Edexcel IAL WME01 June 2025 Q8a–d, condensed.)* Two small balls P (mass kM) and Q (mass $3M$), $k < 3$, are attached to the ends of a light inextensible string which passes over a fixed light smooth pulley. The balls are held at rest with the hanging parts of the string vertical and released. P moves with acceleration of magnitude $\frac{1}{5}g$. (a) Write down the equation of motion for P. (b) Find k. (c) Given $M = 0.5$ kg, find the magnitude of the force exerted on the pulley by the string while Q is moving down. (d) At release, P is more than 2.5 m below the pulley and Q is 2.5 m above horizontal ground. After Q hits the ground it rebounds with speed $0.4\ \mathrm{m\,s^{-1}}$. Find the magnitude of the impulse Q receives when it hits the ground. [11]

Solutions

2.1 Equations: $5g - T = 5a$, $T - 3g = 3a$. Adding: $2g = 8a$, so $a = 2.45\ \mathrm{m\,s^{-2}}$; $T = 3(9.8 + 2.45) = 36.75$ N (37).

2.2 Block (along table): $T = 2a$; hanging: $3g - T = 3a$. Adding: $3g = 5a$, so $a = 5.88\ \mathrm{m\,s^{-2}}$; $T = 2(5.88) = 11.76$ N (12).

2.3 The two string parts pull down with T each: force $= 2T = 73.5$ N (74).

2.4 The string goes slack (tension zero), so the only horizontal force on the block is none – it continues at constant speed (Newton I); friction is absent (smooth table). If the table were rough it would decelerate at μg.

3.1 (a) $T - kMg = kM \cdot \frac{g}{5}$. (b) For Q: $3Mg - T = 3M \cdot \frac{g}{5}$. Adding the two equations: $(3 - k)g = \frac{g}{5}(3 + k)$, so $5(3 - k) = 3 + k$, $k = 2$. (c) With $k = 2$, $M = 0.5$: P has mass 1 kg, so $T = 1(g + \frac{g}{5}) = 1.2g = 11.76$ N; force on pulley $= 2T = 23.5$ N (24). (d) Speed on landing: $v^2 = 2(\frac{g}{5})(2.5) = g$, so $v = 3.13\ \mathrm{m\,s^{-1}}$. Impulse (reversal): $I = 1.5(3.13 + 0.4) = 5.3$ N s (5.30).

Local review guidance: paired equations with the correct mass on the right of each; k found exactly; $2T$ for the pulley with the landing speed from the descent phase; impulse using velocity change with signs. This is authored classroom guidance.