5.3 Newton's laws and friction

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

KEY WORDS normal reaction • coefficient of friction

Newton's laws and friction

Objective

Apply $F = ma$ to single bodies along and perpendicular to the motion, include resistance and friction $F = \mu R$ on horizontal and inclined planes, and handle forces at angles (objectives 4.1, 4.4).

1 Key knowledge and worked examples

Rules of the road. Draw the diagram; resolve perpendicular (usually $R = mg\cos\theta$ or $R = mg - T\sin\alpha$) and along the motion; every term signed. Friction opposes motion with $F = \mu R$ when sliding. $\tan\theta = \frac{3}{4}$ means $\sin\theta = \frac{3}{5}$, $\cos\theta = \frac{4}{5}$ – use the fractions, not decimals.

Worked example – two ropes at angles (WME01 June 2025 Q4). Forces 800 N at 25° above the line of motion and 500 N at α below it keep a 15000 kg barge moving straight: perpendicular equilibrium $800\sin 25° = 500\sin\alpha$ gives $\alpha = 43°$; along the motion, with resistance 750 N, $800\cos 25° + 500\cos\alpha - 750 = 15000a$ gives $a = 0.023\ \mathrm{m\,s^{-2}}$.

2 Practice

2.1 A 4 kg block slides on a smooth horizontal surface under a 20 N horizontal force. Find its acceleration and the normal reaction. [3]

2.2 The surface is now rough with $\mu = 0.25$. Find the acceleration under the same 20 N force. [4]

2.3 A person of mass 80 kg stands in a lift accelerating upwards at $1.5\ \mathrm{m\,s^{-2}}$. Find the normal reaction from the lift floor. [4]

2.4 An 8 kg crate on rough horizontal ground ($\mu = 0.4$) is pulled by a rope at 30° above the horizontal with tension 50 N. Find its acceleration. [4]

3 Exam-style questions

3.1 *(Edexcel IAL WME01 June 2025 Q4.)* Two ropes are attached to a point on the front of a barge of mass 15 tonnes. The barge is pulled along a straight canal by a horizontal force of 800 N acting at 25° to the direction of motion and a horizontal force of 500 N acting at $\alpha°$ to the direction of motion, on the other side of it. The barge accelerates along the canal, and the total resistance to motion is 750 N. (a) Find α. (b) Find the acceleration of the barge. [7]

3.2 *(Edexcel IAL WME01 June 2025 Q6c.)* A package of mass 2 kg is held at rest on a rough plane inclined at θ to the horizontal, where $\tan\theta = \frac{3}{4}$, by a force of X N directed up the plane along a line of greatest slope. The coefficient of friction between the package and the plane is $\frac{1}{4}$. Find the smallest possible value of X. [3]

Solutions

2.1 $a = \frac{20}{4} = 5\ \mathrm{m\,s^{-2}}$; $R = 4g = 39.2$ N.

2.2 $R = 39.2$ N, friction $= 0.25(39.2) = 9.8$ N; $a = \dfrac{20 - 9.8}{4} = 2.55\ \mathrm{m\,s^{-2}}$ (2.6).

2.3 $R - 80g = 80(1.5)$, so $R = 80(9.8 + 1.5) = 904$ N.

2.4 Perpendicular: $R = 8g - 50\sin 30^\circ = 78.4 - 25 = 53.4$ N. Friction $= 0.4(53.4) = 21.36$ N. Along: $50\cos 30^\circ - 21.36 = 8a$, so $a = \dfrac{43.30 - 21.36}{8} = 2.74\ \mathrm{m\,s^{-2}}$ (2.7).

3.1 (a) No acceleration perpendicular to the canal: $800\sin 25^\circ = 500\sin\alpha$, so $\sin\alpha = \frac{800(0.4226)}{500} = 0.676$ and $\alpha = 43^\circ$ (nearest degree). (b) Along the canal: $800\cos 25^\circ + 500\cos 42.55^\circ - 750 = 15000a$: $725.0 + 368.1 - 750 = 343.1 = 15000a$, so $a = 0.023\ \mathrm{m\,s^{-2}}$.

3.2 Least X when friction acts UP the slope at its limit (helping hold the package). Perpendicular: $R = 2g\cos\theta = 2(9.8)(\frac{4}{5}) = 15.68$ N; friction $= \frac{1}{4}(15.68) = 3.92$ N. Along: $X = 2g\sin\theta - 3.92 = 2(9.8)(\frac{3}{5}) - 3.92 = 11.76 - 3.92 = 7.84$ N $(= \frac{4}{5}g)$.

Local review guidance: resolution both perpendicular and along, all terms present and signed; friction μR only once R is found; answers to 2–3 s.f. with units, or as exact multiples of g when the question says "show". This is authored classroom guidance.