A Level Mechanics
Practice Test 2: Newton's Laws of Motion

Instructions:
Answer all questions. Show your working clearly.
Calculators may be used unless stated otherwise.
Draw diagrams where appropriate to illustrate your solutions.
Time allowed: 2 hours 20 minutes

Section A: Advanced Newton's Laws Theory [25 marks]

Question 1 [**15 marks**]

(a) Explain what is meant by an "inertial reference frame" and why Newton's laws are only valid in such frames. [**4 marks**]

(b) A car accelerates forward. Describe and explain the forces acting on a passenger inside the car from both the car's reference frame and an observer on the ground. [**5 marks**]

(c) State the principle of superposition as it applies to forces and give an example. [**3 marks**]

(d) Explain why it is impossible to have a single isolated force in nature. [**3 marks**]

Question 2 [**10 marks**] A block of mass 8 kg sits on a rough horizontal surface with coefficient of static friction 0.5 and kinetic friction 0.3.

(a) Calculate the range of horizontal forces that can be applied without the block moving. [**3 marks**]

(b) If a force of 50 N is applied horizontally, determine the motion of the block. [**4 marks**]

(c) Explain why the transition from static to kinetic friction often causes a sudden jerk in motion. [**3 marks**]

Section B: Complex Force Systems [30 marks]

Question 3 [**18 marks**] A uniform ladder of mass 20 kg and length 5 m leans against a smooth vertical wall at an angle of 60° to the horizontal. The coefficient of static friction between the ladder and the ground is 0.4.

(a) Draw a clear free body diagram for the ladder. [**4 marks**]

(b) Write down the equilibrium conditions for forces and moments. [**4 marks**]

(c) Calculate the normal forces at the ground and wall. [**5 marks**]

(d) Determine the friction force at the ground and verify it doesn't exceed the maximum possible. [**3 marks**]

(e) Find the minimum coefficient of friction needed to prevent slipping. [**2 marks**]

Question 4 [12 marks] Three forces act on a particle: $\vec{F_1} = 12\hat{i} + 5\hat{j}$ N, $\vec{F_2} = -8\hat{i} + 15\hat{j}$ N, and $\vec{F_3} = 6\hat{i} - 10\hat{j}$ N.

(a) Calculate the net force on the particle. **[3 marks]**

(b) If the particle has mass 2 kg, find its acceleration vector. **[2 marks]**

(c) Calculate the magnitude and direction of the acceleration. **[4 marks]**

(d) What additional force would be needed to keep the particle in equilibrium? **[3 marks]**

Section C: Advanced Inclined Plane Problems [25 marks]

Question 5 [15 marks] A block of mass 10 kg is placed on an inclined plane that makes an angle with the horizontal. The coefficient of static friction is 0.6 and kinetic friction is 0.4.

(a) Find the maximum angle at which the block will remain stationary. **[4 marks]**

(b) If the angle is increased to 40°, calculate the acceleration down the plane. **[5 marks]**

(c) A horizontal force of 30 N is now applied to prevent the block sliding down the 40° incline. Determine if this force is sufficient. **[6 marks]**

Question 6 [10 marks] Two blocks of masses 6 kg and 4 kg are connected by a light string over a pulley at the top of an inclined plane. The 6 kg block is on a smooth incline of 30°, while the 4 kg block hangs vertically.

(a) Draw free body diagrams for both blocks. **[3 marks]**

(b) Calculate the acceleration of the system. **[4 marks]**

(c) Find the tension in the string. **[3 marks]**

Section D: Multi-Body Systems [30 marks]

Question 7 [18 marks] A truck of mass 2000 kg pulls a trailer of mass 800 kg. The truck's engine provides a driving force of 3600 N, and both vehicles experience a resistance force of 200 N each.

(a) Calculate the acceleration of the truck-trailer system. **[4 marks]**

(b) Find the tension in the coupling between truck and trailer. **[5 marks]**

(c) If the truck and trailer travel up a slope of 10°, recalculate the acceleration. **[5 marks]**

(d) Determine the new tension in the coupling on the slope. **[4 marks]**

Question 8 [12 marks] Three masses are connected by light inextensible strings: 2 kg and 3 kg on a smooth horizontal surface, with the 3 kg mass connected over a pulley to a hanging 4 kg mass.

(a) Draw clear free body diagrams for all three masses. **[4 marks]**

(b) Calculate the common acceleration of the system. **[4 marks]**

(c) Find the tension in each string segment. **[4 marks]**

Section E: Friction and Motion Analysis [28 marks]

Question 9 [**15 marks**] A crate of mass 25 kg is pulled across a horizontal floor by a rope that makes an angle of 37° above the horizontal. The coefficient of kinetic friction is 0.25.

(a) Draw a free body diagram showing all forces. [**3 marks**]

(b) If the tension in the rope is 120 N, calculate the normal force from the floor. [**4 marks**]

(c) Find the friction force acting on the crate. [**3 marks**]

(d) Calculate the acceleration of the crate. [**5 marks**]

Question 10 [**13 marks**] A box slides down a rough inclined plane of angle 35°. Starting from rest, it travels 12 m in 4 seconds.

(a) Calculate the acceleration down the plane. [**3 marks**]

(b) Determine the coefficient of kinetic friction between box and plane. [**5 marks**]

(c) Find the speed of the box after traveling 12 m. [**2 marks**]

(d) Calculate the time taken to travel the next 12 m. [**3 marks**]

Section F: Circular Motion and Forces [25 marks]

Question 11 [**15 marks**] A car of mass 1200 kg travels around a horizontal circular track of radius 80 m at constant speed.

(a) If the car takes 20 seconds to complete one lap, calculate its speed. [**3 marks**]

(b) Determine the centripetal acceleration. [**3 marks**]

(c) Find the centripetal force required. [**2 marks**]

(d) If the maximum static friction is 8000 N, calculate the maximum safe speed. [**4 marks**]

(e) What banking angle would allow the car to travel at 25 m/s without relying on friction? [**3 marks**]

Question 12 [**10 marks**] A conical pendulum consists of a mass of 0.5 kg attached to a string of length 1.2 m. The mass moves in a horizontal circle of radius 0.8 m.

(a) Calculate the angle the string makes with the vertical. [**2 marks**]

(b) Find the tension in the string. [**4 marks**]

(c) Calculate the speed of the mass. [**4 marks**]

Section G: Elevator and Lift Problems [22 marks]

Question 13 [**12 marks**] A person of mass 70 kg stands on a scale in an elevator that moves with varying acceleration.

(a) Calculate the scale reading when the elevator accelerates upward at 2.5 m/s². [**3 marks**]

(b) Find the scale reading when the elevator accelerates downward at 1.8 m/s². [**3 marks**]

(c) What acceleration would cause the scale to read 1000 N? [**3 marks**]

(d) Explain why the scale reading changes during acceleration. [**3 marks**]

Question 14 [10 marks] An elevator cable can support a maximum tension of 15,000 N. The empty elevator has mass 800 kg and carries passengers with total mass 600 kg.

(a) Calculate the tension when the elevator moves at constant velocity. **[2 marks]**

(b) Find the maximum upward acceleration possible. **[4 marks]**

(c) Determine the maximum downward acceleration before the cable becomes slack. **[4 marks]**

Section H: Complex Applications [15 marks]

Question 15 [15 marks] A block of mass 5 kg rests on a wedge of mass 10 kg. The wedge angle is 30° and all surfaces are frictionless. The wedge can slide on a horizontal surface.

(a) Draw free body diagrams for both the block and wedge. **[4 marks]**

(b) If the system is released from rest, calculate the acceleration of the wedge. **[6 marks]**

(c) Find the acceleration of the block relative to the ground. **[3 marks]**

(d) Determine the normal force between the block and wedge. **[2 marks]**

Physics Data and Formulae

Newton's Laws:
First Law: $\vec{F}_{net} = 0 \Rightarrow \vec{a} = 0$
Second Law: $\vec{F}_{net} = m\vec{a}$
Third Law: $\vec{F}_{AB} = -\vec{F}_{BA}$

Friction Laws:
Static friction: $f_s \leq \mu_s N$
Kinetic friction: $f_k = \mu_k N$
Rolling friction: $f_r = \mu_r N$

Circular Motion:
Centripetal acceleration: $a_c = \frac{v^2}{r} = \omega^2 r$
Centripetal force: $F_c = \frac{mv^2}{r}$
Banking angle: $\tan\theta = \frac{v^2}{rg}$

Equilibrium Conditions:
Force equilibrium: $\sum \vec{F} = 0$
Moment equilibrium: $\sum \vec{M} = 0$

Kinematic Equations:
$v = u + at$
$s = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2as$

Vector Operations:
Magnitude: $|\vec{F}| = \sqrt{F_x^2 + F_y^2}$
Direction: $\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$

Constants:
Acceleration due to gravity: $g = 9.8$ m/s^2

Trigonometric Values:

$\sin 30 = 0.500$, $\cos 30 = 0.866$, $\tan 30 = 0.577$
$\sin 35 = 0.574$, $\cos 35 = 0.819$, $\tan 35 = 0.700$
$\sin 37 = 0.602$, $\cos 37 = 0.799$, $\tan 37 = 0.754$
$\sin 40 = 0.643$, $\cos 40 = 0.766$, $\tan 40 = 0.839$
$\sin 60 = 0.866$, $\cos 60 = 0.500$, $\tan 60 = 1.732$

END OF TEST

Total marks: 200

Grade boundaries: A* 180, A 160, B 140, C 120, D 100, E 80

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