MARKING GUIDE OF PHYSICS EXAM FOR S4

SECTION A./55marks From 1 to 20 each for 1mark

1. a) A transparent medium bound by one or two curved surfaces (This defines a lens)

2. c) Convex lens (Convex lenses are thicker in the middle)
3. b) The point to which all parallel rays converge after refraction (Principal focus of convex lens)
4. c) 25 cm (Near point of normal human eye)
5. d) Infinity (Far point of normal human eye)
6. c) Both net force and net torque are zero (Conditions for equilibrium)
7. b) When displaced, it returns to its original position (Definition of stable equilibrium)
8. b) Three concurrent forces in equilibrium (Lami's theorem applies to three forces)
9. A)20 W (Power = Work/Time = 600J/30s = 20W)
10. b) 2 m/s (Using conservation of momentum: $m_1u_1 + m_2u_2 = (m_1+m_2)v \rightarrow 2\times4 + 2\times0 = 4v \rightarrow v = 8/4 = 2$ m/s)
11. b) 1 Ω (For parallel resistors: $1/R = 1/2 + 1/3 + 1/6 = 3/6 + 2/6 + 1/6 = 6/6 = 1 \rightarrow R = 1\Omega$)
12. b) Charge (Kirchhoff's junction rule: sum of currents entering = sum leaving, based on charge conservation)
13. c) Energy (Kirchhoff's loop rule: sum of EMFs = sum of voltage drops, based on energy conservation)
14. b) 0.5 A ($I = EMF/(R+r) = 1.5V/(2.5\Omega+0.5\Omega) = 1.5/3 = 0.5A$)
15. c) Methane gas from Lake Kivu (Rwanda's main fossil fuel resource)
16. c) Heat within the earth (Geothermal energy source)
17. c) They are environmentally friendly and sustainable (Main advantage of renewable energy)
18. b) Energy flow and transformations (Sankey diagrams show energy transfers)
19. b) 17.3 m/s ($v_x = v \cos\theta = 20 \times \cos30° = 20 \times 0.866 = 17.3$ m/s)
20. A)8 m/s² ($a_c = v^2/r = 4^2/2 = 16/2 = 8$ m/s²)

Part II

22. PROJECTILE MOTION PROBLEM

Given:

Height of building: h = 45 m

Initial velocity: u = 20 m/s

Launch angle: θ = 30°

$g = 9.8$ m/s²

(a) Time to reach ground:

Initial vertical velocity: $u_y = u \sin\theta = 20 \times \sin30° = 20 \times 0.5 = 10$ m/s (upward)

Using $s = u_y t + \frac{1}{2}gt^2$ (taking downward as positive, so s = +45 m, $u_y = -10$ m/s)

$45 = -10t + \frac{1}{2}(9.8)t^2$

$4.9t^2 - 10t - 45 = 0$

Using quadratic formula: $t = [10 \pm \sqrt{(100 + 4\times4.9\times45)}]/(2\times4.9)$

$t = [10 \pm \sqrt{(100 + 882)}]/9.8$

$t = [10 \pm \sqrt{982}]/9.8$

$t = [10 \pm 31.34]/9.8$

Taking positive root: $t = (10 + 31.34)/9.8 = 41.34/9.8 = 4.22$ seconds

(b) Horizontal distance:

Horizontal velocity: $u_x = u \cos\theta = 20 \times \cos30° = 20 \times 0.866 = 17.32$ m/s

Range = $u_x \times t = 17.32 \times 4.22 = 73.1$ m

(c) Velocity just before impact:

Vertical velocity at impact: $v_y = u_y + gt = -10 + (9.8 \times 4.22) = -10 + 41.36 = 31.36$ m/s (downward)

Magnitude: $v = \sqrt{(v_x^2 + v_y^2)} = \sqrt{(17.32^2 + 31.36^2)} = \sqrt{(300 + 983)} = \sqrt{1283} = 35.8$ m/s

Direction: $\theta = \tan^{-1}(v_y/v_x) = \tan^{-1}(31.36/17.32) = \tan^{-1}(1.81) = 61.1°$ below horizontal

23. PLANO-CONVEX LENS WITH LIQUID

Given:

Refractive index of lens: $n = 1.5$

Without liquid: Object and image coincide at 10 cm

With liquid: Object and image coincide at 100 cm

When object and image coincide, the rays must be retracing their path, meaning the lens-mirror combination behaves like a concave mirror with the object at the center of curvature.

Without liquid: The focal length of the combination $f_1 = R/2 = 10$ cm, so $R = 20$ cm

For a plano-convex lens, the focal length is given by: $1/f = (n-1)(1/R_1 - 1/R_2)$

For plano-convex: $R_1 = R$ (curved surface), $R_2 = \infty$, so:

$1/f = (n-1)/R$

Without liquid (lens in air): $1/f_1 = (1.5-1)/R = 0.5/R$

Since $f_1 = 10$ cm: $1/10 = 0.5/R \rightarrow R = 5$ cm? Wait, this contradicts our earlier deduction.

Let's reconsider: When the lens is placed on a mirror, the effective focal length of the combination is $f_{eff} = R/2$ (for a concave mirror formed by the lens-mirror system). So $R = 2 \times 10 = 20$ cm.

Now with liquid between lens and mirror:

The liquid acts as a second lens. The effective focal length $f_2 = 100$ cm (since object and image coincide at 100 cm, meaning radius of curvature = 100 cm).

The power of the combination: $P_{total} = P_{lens} + P_{liquid}$ (since they're in contact)

P_{lens} in air $= (n-1)/R = 0.5/0.2 = 2.5$ D (if R=0.2 m)

But this doesn't match $f_1=0.1$ m which gives P=10 D.

Let's use the lensmaker's formula correctly:

$1/f = (n-1)(1/R_1 - 1/R_2)$

For plano-convex: $R_1 = R$, $R_2 = \infty$

$1/f = (n-1)/R$

Without liquid: $f_1 = 0.1$ m, $n = 1.5$

$1/0.1 = (1.5-1)/R$

$10 = 0.5/R$

$R = 0.05$ m = 5 cm

Then with liquid: The combination acts like a mirror with radius 100 cm. For a lens-mirror system, the effective focal length $f_{eff} = R/2 = 50$ cm.

But the liquid changes the optical path. When liquid is present, the light passes through lens, then liquid, reflects off mirror, returns through liquid and lens. The effective focal length is given by:

$1/f_{eff} = 2/f_{lens} + 2/f_{liquid}$

Where $f_{liquid} = R/(n_{liquid} - 1)$ for the plano-concave liquid lens (since liquid forms a plano-concave lens with the mirror)

So: $1/0.5 = 2/0.1 + 2/f_{liquid}$

$2 = 20 + 2/f_{liquid}$

$2/f_{liquid} = 2 - 20 = -18$

$f_{liquid} = -2/18 = -0.111$ m $= -11.1$ cm

For a plano-concave lens: $1/f_{liquid} = -(n_{liquid} - 1)/R$

$-1/0.111 = -(n_{liquid} - 1)/0.05$

$-9 = -(n_{liquid} - 1)/0.05$

$9 \times 0.05 = n_{liquid} - 1$

$0.45 = n_{liquid} - 1$

$n_{liquid} = 1.45$

Refractive index of liquid = 1.45

24. ELASTIC COLLISION

Given:

$m_A = 0.500$ kg, $m_B = 0.300$ kg

$u_A = 4.00$ m/s (positive x-direction), $u_B = 0$

$v_A = 2.00$ m/s at unknown direction

Need to find v_B and angle α

For elastic collision, both momentum and kinetic energy are conserved.

Momentum conservation (x-direction):

$m_A u_A = m_A v_A \cos\theta + m_B v_B \cos\alpha$

$0.5 \times 4 = 0.5 \times 2 \cos\theta + 0.3 \times v_B \cos\alpha$

$2 = \cos\theta + 0.3 v_B \cos\alpha$ ...(1)

Momentum conservation (y-direction):

$0 = m_A v_A \sin\theta - m_B v_B \sin\alpha$ (assuming v_B has positive y-component)

$0 = 0.5 \times 2 \sin\theta - 0.3 v_B \sin\alpha$

$0 = \sin\theta - 0.3\, v_B \sin\alpha$ ...(2)

Kinetic energy conservation:

$\frac{1}{2} m_A u_A^2 = \frac{1}{2} m_A v_A^2 + \frac{1}{2} m_B v_B^2$

$0.5 \times 16 = 0.5 \times 4 + 0.3\, v_B^2$

$8 = 2 + 0.3\, v_B^2$

$6 = 0.3\, v_B^2$

$v_B^2 = 20$

$v_B = \sqrt{20} = 4.47$ m/s

From (2): $\sin\theta = 0.3\, v_B \sin\alpha = 0.3 \times 4.47 \sin\alpha = 1.34 \sin\alpha$

From (1): $2 = \cos\theta + 0.3 \times 4.47 \cos\alpha = \cos\theta + 1.34 \cos\alpha$

Also, $\sin^2\theta + \cos^2\theta = 1$

$(1.34 \sin\alpha)^2 + (2 - 1.34 \cos\alpha)^2 = 1$

Let $k = 1.34$

$k^2 \sin^2\alpha + 4 - 4k \cos\alpha + k^2 \cos^2\alpha = 1$

$k^2(\sin^2\alpha + \cos^2\alpha) + 4 - 4k \cos\alpha = 1$

$k^2 + 4 - 4k \cos\alpha = 1$

$1.8 + 4 - 5.36 \cos\alpha = 1$

$5.8 - 5.36 \cos\alpha = 1$

$5.36 \cos\alpha = 4.8$

$\cos\alpha = 0.896$

$\alpha = 26.3°$

Then $\sin\theta = 1.34 \sin 26.3° = 1.34 \times 0.443 = 0.594$

$\theta = 36.4°$

Final answer: $v_B = 4.47$ m/s at angle $\alpha = 26.3°$

25. Tensions in Cords

Given: Chandelier mass = 200 kg, so weight $W = mg = 200 \times 9.8 = 1960$ N

From the figure (assuming typical setup with two cords at angles):

Let's assume cord A makes angle θ_A with horizontal and cord B makes angle θ_B with horizontal.

For equilibrium:

$\Sigma F_x = 0$: $F_A \cos\theta_A = F_B \cos\theta_B$

$\Sigma F_y = 0$: $F_A \sin\theta_A + F_B \sin\theta_B = 1960$ N

Without specific angles from the figure, I'll provide the general solution:

$F_A = 1960 / [\sin\theta_A + (\cos\theta_A / \cos\theta_B) \times \sin\theta_B]$

$F_B = F_A \cos\theta_A / \cos\theta_B$

26. Kirchhoff's Rules Problem

Given circuit with resistors and batteries (from figure)

Without specific values from the image, I'll outline the method:

(a) Finding currents:

Label currents I_1, I_2, I_3 in each branch with assumed directions

Apply Kirchhoff's junction rule at nodes

Apply Kirchhoff's loop rule for independent loops

Solve the system of equations

(b) Potential difference between C and F:

$V_{CF} = V_C - V_F$ = (sum of voltage drops/rises along path from F to C)

The point at higher potential is the one with greater voltage.

SECTION B.EACH FOR 15MARKS

27. SATELLITE ORBIT PROBLEM

Given:

Altitude: $h = 500$ km $= 5.00 \times 10^5$ m

Satellite mass: $m = 2000$ kg

Earth radius: $R_E = 6370$ km $= 6.37 \times 10^6$ m

Earth mass: $M = 5.98 \times 10^{24}$ kg

$G = 6.67 \times 10^{-11}$ N·m²/kg²

Orbital radius: $r = R_E + h = 6.37 \times 10^6 + 5.00 \times 10^5 = 6.87 \times 10^6$ m

(a) Orbital velocity:

For circular orbit: gravitational force = centripetal force

$GMm/r^2 = mv^2/r$

$v = \sqrt{(GM/r)}$

$v = \sqrt{[(6.67 \times 10^{-11} \times 5.98 \times 10^{24})/(6.87 \times 10^6)]}$

$v = \sqrt{[(3.99 \times 10^{14})/(6.87 \times 10^6)]}$

$v = \sqrt{(5.81 \times 10^7)}$

$v = 7.62 \times 10^3$ m/s $= 7.62$ km/s

(b) Total mechanical energy in orbit:

Kinetic energy: $K = \frac{1}{2}mv^2 = \frac{1}{2} \times 2000 \times (7.62 \times 10^3)^2$

$K = 1000 \times 5.81 \times 10^7 = 5.81 \times 10^{10}$ J

Potential energy: $U = -GMm/r$

$U = -(6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 2000)/(6.87 \times 10^6)$

$U = -(7.98 \times 10^{17})/(6.87 \times 10^6)$

$U = -1.16 \times 10^{11}$ J

Total energy: $E_{orbit} = K + U = 5.81 \times 10^{10} - 1.16 \times 10^{11} = -5.79 \times 10^{10}$ J

On Earth's surface ($r = R_E$):

$U_{surface} = -GMm/R_E = -(6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 2000)/(6.37 \times 10^6)$

$U_{surface} = -(7.98 \times 10^{17})/(6.37 \times 10^6) = -1.25 \times 10^{11}$ J

K_surface = 0 (if at rest relative to Earth's surface)

E_surface = U_surface = -1.25×10^{11} J

(c) Energy provided by rocket:

Energy needed = E_orbit - E_surface = $-5.79 \times 10^{10} - (-1.25 \times 10^{11}) = 6.71 \times 10^{10}$ J

This is less than the sum of (increase in PE + KE in orbit) because:

The satellite already has some KE from Earth's rotation (if launched from equator)

The potential energy increase (ΔU = U_orbit - U_surface = 7.1×10^{9} J) plus orbital KE (5.81×10^{10} J) = 6.52×10^{10} J, which is close to our calculated value

(d) Trajectory analysis:

A gravity turn trajectory is more efficient because:

It uses Earth's gravity to gradually change the rocket's direction

Minimizes gravitational losses (energy spent fighting gravity)

Reduces aerodynamic drag by staying in denser atmosphere for less time

Vertical launch then horizontal turn wastes energy because:

Rocket fights gravity directly for longer

Requires more thrust to maintain vertical velocity

Then needs additional energy to change direction

Energy degradation during launch includes:

Drag losses (heating the atmosphere)

Gravitational losses (potential energy increase)

Steering losses (changing direction)

28. Archer Problem

Given:

Range: R = 70 m

Initial velocity: u = 60 m/s

$g = 9.8$ m/s²

Height requirement: minimum 5 m above ground

(a) Launch angles:

Range equation: $R = (u^2 \sin 2\theta)/g$

$70 = (60^2 \times \sin 2\theta)/9.8$

$70 = (3600 \times \sin 2\theta)/9.8$

$\sin 2\theta = (70 \times 9.8)/3600 = 686/3600 = 0.1906$

$2\theta = \sin^{-1}(0.1906) = 11.0° \text{ or } 180° - 11.0° = 169.0°$

$\theta = 5.5° \text{ or } 84.5°$

(b) Maximum height:

$H = (u^2 \sin^2\theta)/(2g)$

For $\theta = 5.5°$: $\sin 5.5° = 0.0958$

$H = (3600 \times 0.00918)/(19.6) = 33.05/19.6 = 1.69$ m

For $\theta = 84.5°$: $\sin 84.5° = 0.995$

$H = (3600 \times 0.990)/(19.6) = 3564/19.6 = 181.8$ m

(c) Safety analysis:

The low angle (5.5°) gives maximum height of only 1.69 m, which is below the 5 m requirement.

The high angle (84.5°) gives maximum height of 181.8 m, easily clearing 5 m.

Safer angle: 84.5° (high angle) because it clears the height requirement.

Time of flight: $T = (2u \sin \theta)/g$

For $\theta = 5.5°$: $T = (2 \times 60 \times 0.0958)/9.8 = (11.5)/9.8 = 1.17$ s

For $\theta = 84.5°$: $T = (2 \times 60 \times 0.995)/9.8 = (119.4)/9.8 = 12.2$ s

(d) Crosswind effect:

Wind speed: $v_w = 5$ m/s perpendicular to shooting direction

Time of flight for chosen angle (84.5°) = 12.2 s

Deflection = $v_w \times T = 5 \times 12.2 = 61$ m

This is a huge deflection! The arrow would miss the target completely.

Correction needed: The archer must aim into the wind by an angle such that:

$\tan \varphi = v_w/v_x$, where $v_x = u \cos \theta = 60 \times \cos 84.5° = 60 \times 0.0998 = 5.99$ m/s

$\tan \varphi = 5/5.99 = 0.835$

$\varphi = 39.9°$

So the archer must aim about 40° into the wind to compensate.

29. **CONICAL PENDULUM**

Given:

Mass: $m = 120$ g $= 0.12$ kg

String length: $L = 60.0$ cm $= 0.6$ m

Angle from vertical: $\theta = 22.6°$

(a) Free body diagram:

Forces acting:

Tension (T) along the string, upward and inward

Weight (mg) downward

(b) Y-component of tension:

In vertical equilibrium: $T_y = mg$

$T \cos \theta = mg$

$T_y = mg = 0.12 \times 9.8 = 1.176$ N

We know this because there's no vertical acceleration.

(c) X-component of tension:

$T = mg/\cos \theta = 1.176/\cos 22.6° = 1.176/0.923 = 1.274$ N

$T_x = T \sin \theta = 1.274 \times \sin 22.6° = 1.274 \times 0.384 = 0.489$ N

(d) Radius of motion:

r = L sin θ = 0.6 × sin 22.6° = 0.6 × 0.384 = 0.230 m

(e) Speed of the ball:

The horizontal component of tension provides centripetal force:

$T_x = mv^2/r$

$v = \sqrt{(T_x \times r/m)} = \sqrt{(0.489 \times 0.23/0.12)}$

$v = \sqrt{(0.1125/0.12)} = \sqrt{0.9375} = 0.968$ m/s

31. Energy Degradation

(a) Definition:

Energy degradation is the process where useful energy is converted into less useful forms, typically thermal energy, making it harder to utilize for doing work.

Difference from energy conservation:

Energy conservation: Energy cannot be created or destroyed (First Law of Thermodynamics)

Energy degradation: The quality/usefulness of energy decreases over time (Second Law of Thermodynamics)

(b) Thermal energy as most degraded form:

Thermal energy is considered most degraded because:

It is dispersed randomly among many particles

It cannot be completely converted back into other forms of energy

Converting heat to work requires temperature differences and has efficiency limits

Real-life examples:

Car engine: Chemical energy in fuel → kinetic energy + heat (from friction, exhaust, engine cooling)

Light bulb: Electrical energy → light + heat (filament gets hot, warming surroundings)

(c) Sankey diagram for incandescent bulb: