CHAPTER - 03
LAWS OF MOTION & FRICTION

PART I - (JEEMAIN LEVEL)

QUESTIONS

SECTION - I

1. 2 $m_1 = \frac{F}{a_1} = \frac{5}{8}kg.$

$m_2 = \frac{F}{a_2} = \frac{5}{24}kg.$

$M = (\frac{5}{8} + \frac{5}{24})\ kg = (\frac{5}{6})\ kg$

Acceleration produced in M (when the two masses are tied together),

$a = \frac{F}{M} = \frac{5}{\frac{5}{6}} = 6\ ms^{-2}$

2. 2 Mass of bullet = m = 5 mg = 5×10^{-3} kg

Initial velocity of bullet = u = 100 m/s,

Final velocity of bullet = v = 0,

Distance of penetration of the bullet = s = 0.06 m

We know that, the retardation experienced by the bullet is given by,

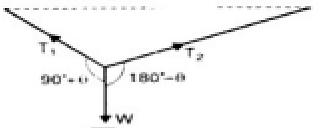
Retardation = a = $\frac{u^2}{2s}$

⇒ Retardation = a = $\frac{u^2}{2s} = \frac{(100)^2}{2 \times 0.06} = \frac{1 \times 10^4}{12 \times 10^{-1}}$

∴ Force = ma = $\frac{5 \times 10^{-3} \times 1 \times 10^5}{12} = \frac{5000}{12} = 417$ N.

Thus, the average force imposed by the bullet on the block is 417 N.

3. 2



$$\frac{T_1}{\sin 180^\circ - \theta} = \frac{T_2}{\sin(90^\circ + \theta)} = \frac{W}{\sin 90^\circ}$$

$\sin\theta = \frac{4}{5}$,

$\cos\theta = \frac{3}{5}$ So,

$T_1 = W\sin\theta = 100 \times 4/5 = 80N$

4. 2 given that $a = g/8$

Now FBD for m_1

$T - m_1 g = m_1(g/8)$ ...(1)

and FBD for m_2

$m_2 g - T = m_2(g/8)$ ...(2)

from (1) and (2)

$g(m_2 - m_1) = \frac{g}{8}(m_1 + m_2)$

$\Rightarrow 8(m_2 - m_1) = m_1 + m_2$

$\Rightarrow 8m_2 - m_2 = m_1 + 8m_1$

$\Rightarrow 7m_2 = 9m_1$

$\Rightarrow \frac{m_2}{m_1} = \frac{9}{7}$

5. 2 Person will feel his weight less when the lift goes down with some acceleration because the pseudo force acting on him is in the upward direction thus reducing the effective gravitational force in the frame of the lift.

6. 2 $F = m(g + a)$

$= 20 \times 10^3(10 + 4)$

$= 28 \times 10^4 N$

7. 1 From above diagram

$AB \sin\theta = h$

$AB \dfrac{h}{\sin\theta}$

$a = g \sin\theta$

A to B

U initial = 0 t= ? a = g Sinθ

and

$S = AB = \dfrac{h}{\sin\theta}$

$= Ut + \frac{1}{2}at^2$

$\dfrac{h}{\sin\theta} = \frac{1}{2}g \sin\theta \times t^2$

$t = \dfrac{1}{\sin\theta}\sqrt{\dfrac{2h}{g}}$

8. 1 Let the acceleration is a and the tension is T.

The acceleration is given as,

$a = \dfrac{F_1 - F_2}{M}$

The tension is given as,

$F_1 - T = ma$

$F_1 - T = \dfrac{M}{L} \times x \times \dfrac{F_1 - F_2}{M}$

$T = F_1 (1 - \dfrac{x}{L}) + F_2 \dfrac{y}{L}$

Thus, the tension is $F_1 (1 - \dfrac{x}{L}) + F_2 \dfrac{x}{L}$.

9. 1 $F_{avg} = m(v_f - v_i)/t$

$v_f = 0m/s$

$v_i = 12m/s$

Therefore,

$F_{avg} = m(v_f - v_i)/t$

$= 0.5(0 - 12)/0.25$

$= -24N$

10. 2 Let a is the initial downward acceleration of the upper block of mass 2m.

before breaking of string, $T = 2mg + kx$

& $kx = mg$

Now, after the string is cut, the forces on the 2m block are:

2mg and kx (= mg)

the equation of motion of the mass 2m is ,

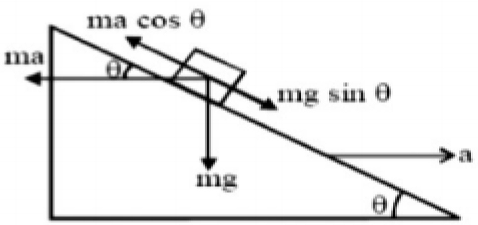
$2ma = (2m + m)g$

$\therefore a = \frac{3g}{2}$

11. 3 The block will remain stationary when resultant force along the incline plane is zero.

$ma\cos\theta = mg\sin\theta$

$a = g\tan\theta$



12. 2 Given that,

Mass of rocket $m = 5000$ Kg

Acceleration $a = 20\ m/s^2$

Speed $v = 800\ m/s$

$g = 10\ m/s^2$

Now, thrust force on the rocket

$$F_t = v_r\left(\frac{-dm}{dt}\right)$$

Net force on the rocket

$$F_{net} = F_t - W$$

$$ma = v_r\left(\frac{-dm}{dt}\right) - mg$$

$$\left(\frac{dm}{dt}\right) = \frac{m(g + a)}{v_r}$$

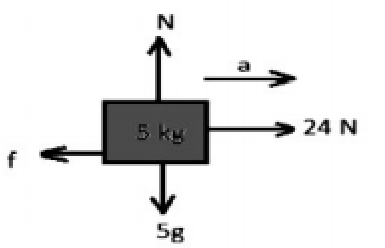
Rate of gas ejected per second

$$\left(\frac{dm}{dt}\right) = \frac{5000\,(10 + 20)}{800}$$

$$\frac{-dm}{dt} = 187.5\ kg/s$$

Hence, the amount of gas ejected per second is 187.5 kg/s

13. 4 The FBD can be shown as given below.



Given, coefficient of kinetic friction $\mu_k = 0.4$

$\therefore$ we have friction force

$f = \mu_k . N = \mu_k . mg = 0.4 \times 5 \times 9.8$

Hence, acceleration of the mass is

$$a = \frac{F_{net}}{m} = \frac{24 - f}{m} = \frac{24 - 19.6}{5} = 0.88\ m s^{-2}$$

14. 4 Initial velocity $u = \frac{p}{m}$

Final velocity $v = 0$ (as the vehicle must stop)

Force of friction = μmg

(where g is acceleration due to gravity)

Acceleration due to friction $= -\frac{\mu mg}{m} = -\mu g$

($-$ve sign shows that it is retardation)

Using the kinematic expression

$v^2 = u^2 = 2as$

and inserting various values we get stopping distance s

$(0)^2 - \frac{p^2}{m^2} = 2(-\mu g)s$

$\Rightarrow s = \frac{p^2}{2m^2 \mu g}$

15. 1

Fig. shows all the forces acting on a block of mass m.

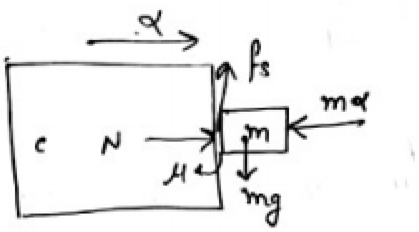
$m\alpha$ = pseudo force

frictional force, $f_s \geq mg$

$\mu N \geq mg$

$\mu m\alpha \geq mg$

$\alpha \geq \frac{g}{\mu}$



16. 3 The minimum force required to start pushing a body up a rough inclined plane is

$F_1 = mg\sin\theta + \mu g\cos\theta$ ......(i)

Minimum force needed to prevent the body from sliding down the inclined plane is

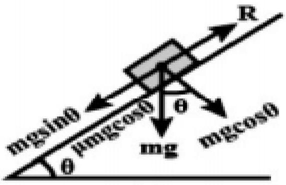
$F_2 = mg\sin\theta - \mu g\cos\theta$ ....(ii)

Divide (i) by (ii), we get

$$\frac{F_1}{F_2} = \frac{\sin\theta + \mu\cos\theta}{\sin\theta - \mu\cos\theta} = \frac{\tan\theta + \mu}{\tan\theta - \mu} = \frac{2\mu + \mu}{2\mu - \mu} = 3$$

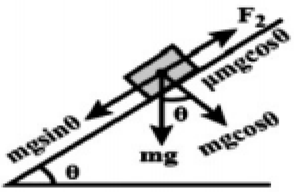
$\tan\theta = 2\mu$ (given))

(i)



(a)

(ii)



(b)

17. 3) $a' = \mu g = 0.5 \times 10 = 5m/s^2$

If acceleration of the truck $a_0 \le \mu g$, the truck and the block move together.

(i) $a_0 = 2m/s^2$, acceleration of the block $= a_0$

$f = 2a_0 = 2 \times 2 = 4N$

(ii) $a_0 = 4m/s^2$

$f = 2a_0 = 2 \times 4 = 8N$

(iii) $a_0 = 6m/s^2 > \mu g$, the block will move in the backward direction with respect to the truck

$N_0 = 20N$

$f_{max} = \mu N = 0.5 \times 20 = 10N$

(b) $a_0 = 8m/s^2 > \mu g$, the block will move in the backward direction w.r.t. the truck

$10 = 2a \Rightarrow a = 5m/s^2$

Acceleration of the block w.r.t. the truck is in the backward direction.

$a_1 = a_0 - a = 8 - 5 = 3m/s^2$

$s = \frac{1}{2}a_1t^2 \Rightarrow 6 = \frac{1}{2} \times 3 \times t^2 \Rightarrow t = 2s$

The block will fall off the truck in $2s$. Distance travelled by the truck in this time.

$s' = \frac{1}{2}a_0t^2 = \frac{1}{2} \times 8 \times 2^2 = 16m$

18. 3 Maximum speed, which a car turning the bend may have without skidding, $v_{max} = \sqrt{\mu r g}$

$= \sqrt{0.8 \times 100 \times 9.8}$

= 28 m/s

SECTION - II

Numerical Type Questions

19. 2 Suppose the man pulls the rope with constant force $ved(F)$ downwards then equation of motion

for point B will be

$F + m_B g - T = m_B a$

i.e., $F = T[as m_B = 0]$ ...(i)

Whiel for painter

$R + T - mg = ma$

$i.e., R + T = m(g + a)$ ....(ii)

And for the system

$2T - (m + M)g = (m + M)a$

i.e., $2T = (m + M)(g + a)$ ....(iii)

Here $m = 100kgM = 25kg, R = A = 450N$

and $g = 10m/s^2$

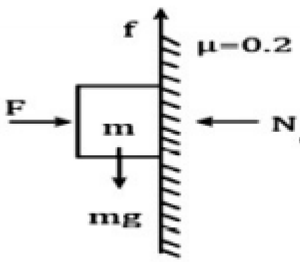
So, from eqns. (ii) and (iii) we have

$450 + T = 100(10 + a)$ and $2T = (100 + 25)(10 + a)$

i.e., $T = 550 + 100a$ and $2T = 125(10 + a)$

$a = 2m/s^2$ a

20. 25

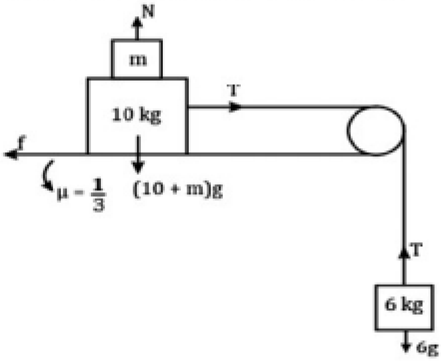


Given:

$\mu_s = 0.2$
$m = 0.5$ kg
$g = 10$ m/s^2

In equilibrium,
$mg = f$
$\Rightarrow mg = \mu_s N = \mu_s F$
$\Rightarrow F = \frac{mg}{\mu_s} = \frac{0.5 \times 10}{0.2} = 25$ N

21. 8 The correct option is **B** 8 kg



For equilbrium,
$N = (10 + m)g$,
$T = 6g$
Friction force,
$f = \mu N = \frac{1}{3}[10 + m]g$
for the blocks to remain at rest,
$T = f$ and $f \le \mu N$
$\Rightarrow 6g \le \frac{(10 + m)g}{3}$
$\Rightarrow 18 \le (10 + m) \Rightarrow m \ge 8$ kg

22. 2

PART - II (JEE ADVANCED LEVEL)

SECTION - III (One correct answer)

23. D $N =$ weight of 2kg and 3kg
$= (2+3)g = 5g = 5 \times 10 = 50N$
option (D)

24. C

$mg - T = ma$

$mg - T_{max} = ma_{min}$

$mg - \frac{3}{4}mg = ma_{min}$

$a_{min} = g/4$ option (c)

25. D

$a = F/2m$

$2F - N\cos 60 = ma$

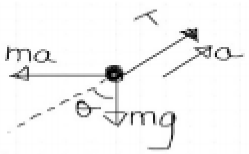
$2F - N/2 = m \times F/2m$

$2F - N/2 = F/2$

$3F/2 = N/2$

$\underline{N = 3F}$

26. C



$\cancel{m}a\cos\theta = \cancel{m}g\sin\theta$

$a = g\tan\theta$

$\tan\theta = a/g$

$T - mg\cos\theta - ma\sin\theta = ma$

$T - mg\frac{g}{\sqrt{g^2+a^2}} - ma\frac{a}{\sqrt{g^2+a^2}} = ma$

$T - m\sqrt{g^2+a^2} = ma$

$T = m\sqrt{g^2+a^2} + ma$

27. D

i) $mg\sin\theta - m$...

$\therefore a = g\sin\theta$

where a is along the inclined plane

$\therefore$ vertical component of acceleration is $g\sin^2\theta$

$\therefore$ relative vertical acceleration of A with respect to B is

$g(\sin^2 60 - \sin^2 30] = \frac{g}{2} = 4.9$ m/s^2 in vertical direction

28. A

'A' remains in equilibrium.

$F = T + f_{A(max)}$

$T = F - f_{A(max)}$

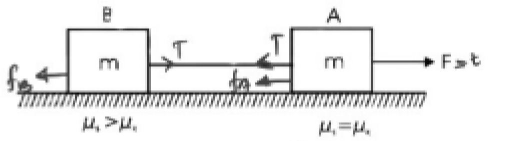
'B' remains in equilibrium

$f_B = T$

$f_B = F - f_{A(max)}$

$f_B = t - f_{A(max)}$

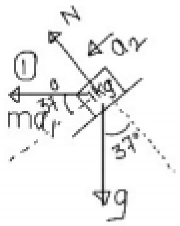
'f_B' will increase linearly until $f_B = f_{max,B}$. $\Rightarrow$ Once $f_B = f_{max,B}$ Kinetic friction begins to act which is less than maximum static friction.



$f_B = 0$ when $F = t = f_{A(max)}$

SECTION - IV (More than one correct answer)

29. ABC



$1 a_1 \cos 37 + g \sin 37 = 1 \times a_2$

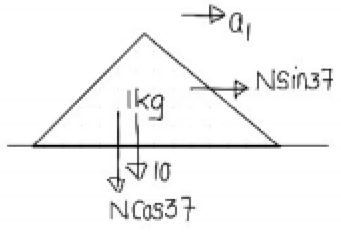
$a_1 \times 4/5 + g \times 3/5 = a_2$

$4a_1 + 3g = 5a_2$

$N + ma_1 \sin 37 = mg \cos 37$

$N + a_1 \times 3/5 = g \times 4/5$

$5N = 4g - 3a_1$



$N \sin 37 = 1 \times a_1$

$N \times 3/5 = a_1$

$N = 5a_1/3$

$5 \times 5a_1/3 = 4g - 3a_1$

$25a_1/3 + 3a_1 = 4g$

$\frac{34a_1}{3} = 4g$

$a_1 = 6g/17$

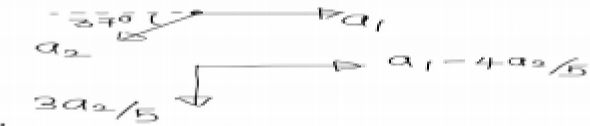
$4a_1 + 3g = 5a_2$

$4 \times 6g/17 + 3g = 5a_2$

$\frac{24g + 51g}{17} = 5a_2$

$\frac{75g}{17} = 5a_2$

$a_2 = \frac{15g}{17}$



$$\tan\theta = \frac{3a_2}{5a_1 - 4a_2}$$
$$= \frac{3 \times 15g}{5 \times 6g - 4 \times 15g}$$
$$= \frac{45g}{-30g} = -1.5$$
$$|\tan\theta| = 1.5$$

30. ABCD **Sol.** The system is in equilibrium:

$$kx_3 = mg \qquad \text{(i)}$$

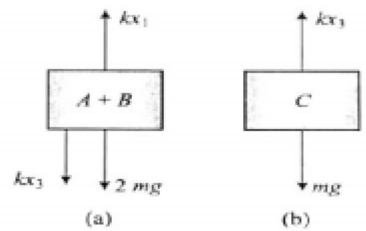


Fig. 6.216

From Fig. 6.216(a),

$$2mg + kx_3 = kx_1 \qquad \text{(ii)}$$

From Fig. 6.216(b),

$\therefore$ $3mg = kx_1$

a. When the spring between ceiling and block is cut, then the elongation of spring between B and C remains same just after cutting.

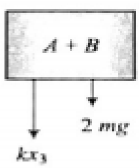


Fig. 6.217

$\therefore$ $a_c = 0$ $(\,kx_3 = mg)$

For $(A + B)$

$$kx_3 + 2mg = 3mg$$

$\therefore$ $3mg = 2ma$

$\therefore$ $a = \dfrac{3}{2}g = 15\ \text{m s}^{-2}$

$\therefore$ $a_A = a_B = 15\ \text{m s}^{-2}$

For tension (from FBD of B).

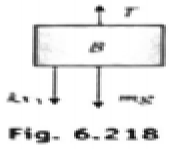


Fig. 6.218

$$mg + kx_3 - T = ma_B$$

$$mg + mg - T = \frac{3mg}{2}$$

$$\therefore \quad T = \frac{mg}{2}$$

(b) When string between A and B is cut, the elongation in springs do not change just after cutting the string.

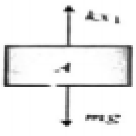


Fig. 6.219

$$mg - kx_1 = ma_A$$
$$mg - 3mg = ma_A \qquad \{kx_1 = 3mg\}$$
$$-2mg = ma_A$$
$$a_A = -2g$$
$$\therefore \quad a_A = 2g \text{ (upward)}$$

For B

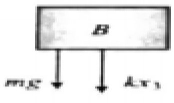


Fig. 6.220

$$mg + kx_3 = m\,a_B$$
$$mg + mg = m\,a_B \qquad \{\therefore kx_3 = mg\}$$
$$\therefore \quad a_A = 2g \quad \text{(downward)}$$

For C,

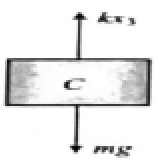


Fig. 6.221

$$mg - kx_3 = ma_C$$
or $$mg - mg = ma_C \qquad \{kx_3 = mg\}$$
$$a_C = 0$$
$$T = 0$$

(c) When spring between B and C is cut.

For C, $mg = ma_C$

$\therefore \quad a_c = g \quad$ (downward)

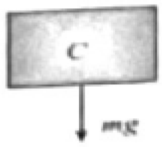


Fig. 6.232

The acceleration of A and B will be equal; taking "$A + B$" together as system

$$2mg - kx_1 = 2ma_B \qquad [\therefore a_A = a_B]$$

$$2mg - 3mg = 2ma_B \qquad [\therefore kx_1 = 3mg]$$

$\therefore \quad a_B = -\dfrac{g}{2}$

$\therefore \quad a_A = a_B = \dfrac{g}{2}$ (upward)

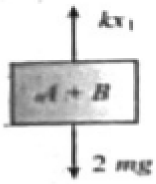


Fig. 6.223

For tension in string between A and B, considering the FBD of B only

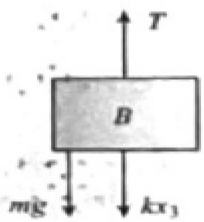
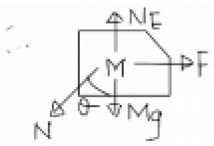


Fig. 6.224

$$T - (mg) = ma_B$$

$$T = mg + \frac{mg}{2} = \frac{3mg}{2}$$

31. ABCD



$\boxed{N_E = N\cos\theta + Mg}$

$\boxed{F = N\sin\theta}$

$N\cos\theta = mg$

$N\sin\theta = N_\omega$

$\frac{mg}{\cos\theta}\sin\theta = N_\omega$

$N_\omega = mg\tan\theta$

32. AB

33. ACD

$f_{max} = \mu mg = 0.2 \times 2 \times 10 = 4N$

$2kg \Rightarrow 8 - 4 = 2a$

$a_{2kg} = 2m/s^2$

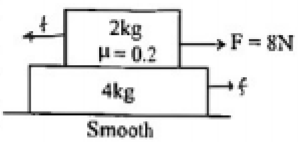
$4kg \Rightarrow 4 = 4a_{4kg}$

$a_{4kg} = 1m/s^2$

✓ A) $a_{2kg\ w.r.t\ 4kg} = a_{2kg} - a_{4kg} = 2 - 1 = 1m/s^2$

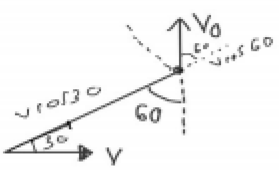
✓ C) $V_{rel} = a_{rel}t = 1 \times 4 = 4m/s$

✓ D) $S_{rel} = \frac{1}{2}a_{rel}t^2 = \frac{1}{2} \times 1 \times 2^2 = 2m$



SECTION - V (Numerical Type - Upto two decimal place)

34. 3



$V_0\cos 60 = V\cos 30$

$V_0 \times \frac{1}{2} = V \times \frac{\sqrt{3}}{2}$

$V = \frac{V_0}{\sqrt{3}}$

$\eta = 3$

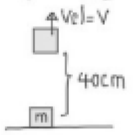
35. 5

36. 6

h = 20cm

dist trav by m = 2x dist trav by 4m

acc of m = $g/2 = 10/2 = 5 m/s^2$



$V^2 = u^2 + 2as$

$V^2 = 2(5)\frac{40}{100}$

$V^2 = 4$

$V = 2 m/s$

from that point its acc = $-g = -10$

$V^2 = u^2 + 2as$

$0 = 4 + 2(-10)S$

$S = 20cm$

$H = 40cm + 20cm$

$H = 60cm$

$H/10 = 6$

37. 8

Block remain stationary.

$f \geq 12N$

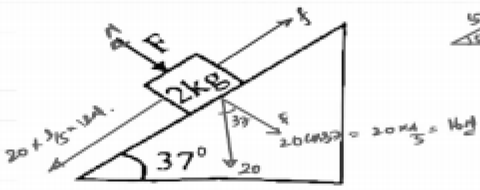
$\mu_s N \geq 12N$

$0.5(F + 16) \geq 12$

$0.5F + 8 \geq 12$

$0.5F \geq 4$

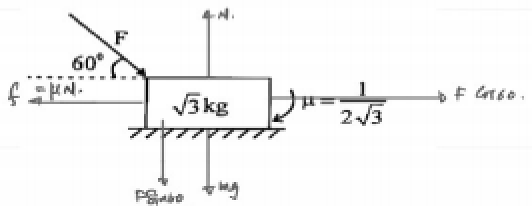
$F \geq \frac{4}{0.5} = 8N$



$F_{min} = \underline{8N}$.

A block A of mass m is placed over a plank B of mass 2 m. Plamck B is placed over a smooth

38. 20



To move the block, $F\cos 60 > f_{max}$.

$\therefore$ For eqbt $\quad \frac{F}{2} \le f_{max}$.

$$\frac{F}{2} \le \mu_s N.$$
$$\frac{F}{2} \le \mu_s\left(mg + F\sin 60\right)$$
$$\frac{F}{2} \le \frac{1}{2\sqrt{3}}\left(\sqrt{3}g + F\times\frac{\sqrt{3}}{2}\right)$$
$$\frac{F}{2} \le \frac{g}{2} + \frac{F}{4}$$
$$\frac{F}{2} - \frac{F}{4} \le \frac{g}{2} \Rightarrow \frac{F}{4} \le \frac{g}{2}$$
$$F \le 2g$$
$$F \le 20N$$
$$F_{max} = \underline{\underline{20N}}.$$

SECTION - VI (Matrix Matching)

39. **i. → a., c. ii. → b., d.**
iii. → a., b., c., d. iv. → c., d.
(i) Force of friction is zero in (a) and (c) because the block has no tendency to move.
(ii) Force of friction is 2.5 N in (b) and (d) because the applied force in horizontal direction in both is 2.5 N.
(iii) Acceleration is zero in all the cases.
(iv) Normal force is not equal to 2 g in (c) and (d) because some extra vertical force is also acting.