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Publication Inc

20 Years
JEE MAIN
Chapter-wise Solved Papers
(2002 - 21)

Corporate Office

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JEE Main Online 2021 Paper February 24, 2021 (M) 2021-1-2021-24

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TREND ANALYSIS FOR JEE MAIN YEAR 2011-2021

JEE Main Entrance Exam for admission into various engineering courses in different engineering colleges and institutes in the country has hit the imagination of the school-going students more than any other entrance test conducted at this level. Without argument, you need to be well-versed with the pattern as well as the level of the questions asked in the exam. A Chapterwise analysis of previous years' questions is called for here, with this objective in mind, we are giving below the chapter-wise analysis (break-up) of the questions asked in last 11 years' of JEE Main

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PHYSICS

Ch. No.	Chapter Name	Number of Question(s) in											
		2011	2012	2013	2014	2015	2016 Ph-1	2017	2018	2019		2020	2021
										9-Jan (M)	9-April (M)	7-Jan (M)	24-Feb (M)
1	Physical World, Units and Measurements	1	2	1	2	1	2	1	1	–	1	–	1
2	Motion in a Straight Line	1	–	–	1	–	–	1	1	–	–	–	1
3	Motion in a Plane	1	2	1	–	1	–	–	–	1	1	0	0
4	Laws of Motion	–	1	2	2	1	–	–	1	1	1	0	2
5	Work, Energy and Power	–	1	1	1	1	2	2	4	2	2	2	1
6	System of Particles and Rotational Motion	2	–	3	1	2	2	2	3	2	2	3	1
7	Gravitation	1	1	1	1	1	1	1	–	1	1	1	3
8	Mechanical Properties of Solids	–	–	–	1	–	–	–	1	–	–	0	1
9	Mechanical Properties of Fluids	2	1	–	3	–	–	1	–	–	1	0	1
10	Thermal Properties of Matter	1	2	1	1	1	1	2	–	2	–	1	1
11	Thermodynamics	1	2	1	1	1	2	–	–	1	1	2	2
12	Kinetic Theory	1	–	–	1	1	–	2	1	1	2	1	0
13	Oscillations	2	2	2	1	2	1	1	1	–	1	0	1
14	Waves	1	1	1	1	1	2	–	1	1	2	1	0
15	Electric Charges and Fields	2	1	1	–	1	1	1	–	2	–	1	1
16	Electrostatic Potential and Capacitance	–	1	–	2	2	1	1	2	1	3	1	1
17	Current Electricity	1	1	2	1	2	1	2	3	4	1	1	2
18	Moving Charges and Magnetism	1	1	1	1	2	2	1	2	1	3	0	0
19	Magnetism and Matter	–	–	1	1	1	1	1	–	2	–	0	0
20	Electromagnetic Induction	1	2	1	–	–	–	1	–	1	1	3	0
21	Alternating Current	2	–	1	1	2	1	1	2	–	–	1	2
22	Electromagnetic Waves	–	1	1	2	–	1	–	1	1	1	1	1
23	Ray Optics and Optical Instruments	2	2	2	1	2	2	1	–	1	1	1	1
24	Wave Optics	1	1	2	1	1	1	2	2	2	1	2	2
25	Dual Nature of Radiation and Matter	1	1	1	1	1	1	2	–	1	1	1	1
26	Atoms	1	1	1	1	1	–	1	2	–	1	1	1
27	Nuclei	2	1	–	–	–	1	1	–	1	–	0	0
28	Semiconductor Electronics : Materials, Devices and Simple Circuits	1	1	1	1	1	3	1	1	1	1	1	2
29	Communication Systems	1	1	1	–	1	1	1	1	–	1	0	1
Total Questions		**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**25**	**30**

CHEMISTRY

Ch. No.	Chapter Name	Number of Question(s) in											
		2011	2012	2013	2014	2015	2016 Ph-1	2017	2018	2019		2020	2021
										9-Jan (M)	9-April (M)	7-Jan (M)	24-Feb (M)
1	Some Basic Concepts of Chemistry	1	–	2	–	1	1	2	1	–	1	1	1
2	Structure of Atom	1	2	1	1	1	1	2	0	1	1	1	1
3	Classification of Elements and Periodicity in Properties	1	–	1	–	1	1	–	0	1	1	1	1
4	Chemical Bonding and Molecular Structure	1	2	3	1	–	1	1	3	1	1	2	1
5	States of Matter	2	1	1	2	1	1		0	1	1	1	0
6	Thermodynamics	2	1	1	1	1	1	2	2	1	1	1	0
7	Equilibrium	2	2	1	1	1	1	1	3	2	–	1	2
8	Redox Reactions	–	–	1	–	1	–	1	1	–	–	1	1
9	Hydrogen	–	1		1	1	2		1	1	1	1	1
10	The s-Block Elements	2	1	2		1	1	1	0	1	1	–	1
11	The p-Block Elements (Group 13 & 14)	1	–	–	–		–	–	2	2	1	–	2
12	Organic Chemistry : Some Basic Principles and Techniques	2	–	2	1	2	2	1	0	–	2	–	0
13	Hydrocarbons	1	2	–	–	1	2	1	1	–	1	–	2
14	Environmental Chemistry	1	1	1	–	–	–	1	1	1	1	–	1
15	The Solid State	1	1	1	2	1	–	1	1	1	–	–	1
16	Solutions	1	2	1	1	1	1	1	1	2	2	1	1
17	Electrochemistry	1	1	2	3	1		1	1	1	1	1	0
18	Chemical Kinetics	1	1	1	1	1	1	1	1	1	1	1	1
19	Surface Chemistry	–	1	1	–	–	1	1	0	1	1	–	1
20	General Principles and Processes of Isolation of Elements	–	1		1	1	1	–	0	1	1	1	1
21	The p-Block Elements (Group 15, 16, 17 and 18)	1	1	–	–	3	2	1	1	–	1	1	0
22	The d and f-Block Elements	–	1	1	2	2	1	1	0	1	1	1	2
23	Coordination Compounds	1	1	1	1	2	2	1	1	1	2	1	1
24	Haloalkanes and Haloarenes		1	1	3	1	2	2	1	–	1	2	1
25	Alcohols, Phenols and Ethers	3	2	2	2		–	1	3	1	–	0	2
26	Aldehydes, Ketones and Carboxylic Acids	–	2	1	1	1	1	3	0	3	2	1	1
27	Amines	1		1	2	1	1	1	1	2	1	1	2
28	Biomolecules	1	1	1	1	1	1	1	2	1	1	1	1
29	Polymers	1	1		1	1	1	1	0	1	1	0	1
30	Chemistry in Everyday Life	1	–	–		1	1		0	–	–	1	0
31	Analytical Chemistry	–	–	–	1	–	–	–	2	1	1	2	0
Total Questions		**30**	**30**	**30**	**30**	**30**	**30**	**35**	**30**	**30**	**30**	**25**	**30**

MATHEMATICS

Ch. No.	Chapter Name	Number of Question(s) in												
		2011	2012	2013	2014	2015	2016 Ph-1	2016 Ph-2	2017	2018	2019		2020	2021
											9-Jan (M)	9-April (M)	7-Jan (M)	24-Feb (M)
1	Sets	0	1	0	0	0	1	0	1	1	–	–	–	–
2	Relations and Functions-1	1	0	0	0	0	0	0	1	0	–	–	–	–
3	Trigonometric Functions	1	1	2	1	1	2	1	1	1	1	2	1	–
4	Principle of Mathematical Induction	0	0	0	0	0	0	0	4	0	–	–	–	–
5	Complex Numbers and Quadratic Equations	2	1	2	2	2	2	1	0	1	2	1	2	2
6	Linear Inequalities	0	0	0	0	0	0	0	2	0	–	–	–	–
7	Permutations and Combinations	1	0	1	1	2	1	1	3	1	1	1	1	1
8	Binomial Theorem	1	1	2	0	2	2	1	0	1	1	1	0	1
9	Sequence and Series	2	2	2	2	2	2	2	0	2	2	2	2	2
10	Straight Lines & Pair of Straight Lines	1	2	2	2	0	1	0	3	2	1	1	2	1
11	Conic Sections	3	3	3	3	4	4	2	1	4	4	4	1	2
12	Limits and Derivatives	1	0	1	1	0	0	1	3	1	1	–	0	1
13	Mathematical Reasoning	1	1	1	1	1	1	1	3	1	1	1	1	1
14	Statistics	1	1	1	1	1	1	0	1	1	1	1	1	–
15	Probability-I	0	1	0	0	0	0	1	1	0	–	–	–	–
16	Relations and Functions-II	1	0	0	1	1	0	2	1	0	1	–	1	1
17	Inverse Trigonometric Functions	0	0	0	0	1	0	1	1	0	1	–	–	–
18	Matrices	1	0	0	0	1	2	1	2	0	–	–	0	1
19	Determinants	1	2	2	2	1	1	3	1	2	1	2	2	2
20	Continuity and Differentiability	2	2	1	1	1	1	1	1	1	1	2	3	1
21	Application of Derivatives	0	1	1	1	2	3	3	2	2	2	3	2	3
22	Integrals	1	2	3	2	2	1	2	2	2	2	3	1	3
23	Applications of Integrals	1	1	1	1	2	1	2	4	1	1	1	1	1
24	Differential Equations	2	1	1	1	1	1	0	0	1	1	1	1	1
25	Vector Algebra	2	2	1	1	1	1	1	3	1	1	1	1	1
26	Three Dimensional Geometry	2	2	2	2	2	2	2	2	2	3	2	1	2
27	Probability-II	2	1	1	3	0	0	0	2	1	1	1	1	2
28	Properties of Triangles	0	2	0	1	0	0	1	1	1	–	–	–	1
Total Questions		**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**25**	**30**

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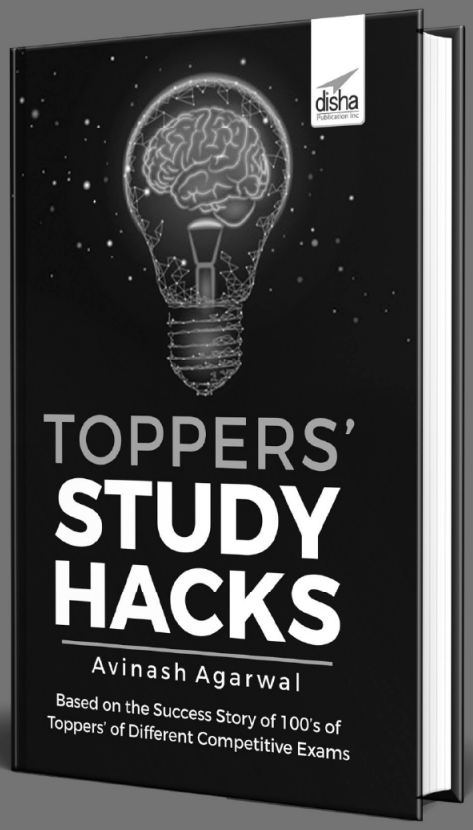
A MUST READ FOR EVERY STUDENT



After interacting with thousands of students and interviewing 100's of Toppers, I realized that most of the students score less not because of lack of knowledge or hard work or intelligence but because of lack of guidance, planned approach and poor study techniques. So, the problem most of the students face is not of potential but of converting that potential into performance. Hard work should bring achievement but only when coupled with efficient and appropriate study techniques and proper strategy.

The book TOPPERS' STUDY HACKS by Avinash Agarwal recapitulates and reinforces the basic strategies adopted by toppers and helps in mastering study skills and techniques for efficient learning.

This book would tell how to develop the right attitude towards an exam and also offer useful suggestions to overcome negativity and improve one's mental endurance and performance in crucial exams like Boards, JEE, NEET, and many more.

JEE MAIN ONLINE 2021 Paper
Held on February 24, 2021 (Morning)

PHYSICS

CHAPTER-1 : PHYSICAL WORLD, UNITS AND MEASUREMENTS

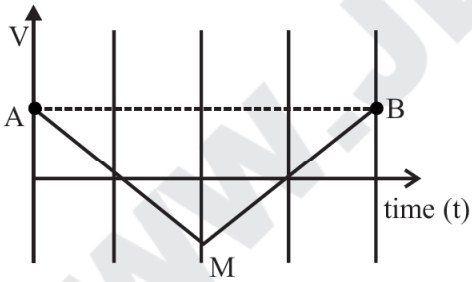
1. The work done by a gas molecule in an isolated system is given by, $W = \alpha\beta^2 e^{-\frac{x^2}{\alpha kT}}$, where x is the displacement k is the Boltzmann constant and T is the temperature, α and β are constants. Then the dimension of β will be :

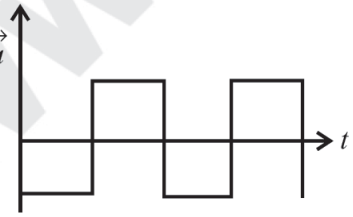
(a) $[ML^2T^{-2}]$ (b) $[MLT^{-2}]$

(c) $[M^2LT^2]$ (d) $[M^0LT^0]$

CHAPTER-2 : MOTION IN A STRAIGHT LINE

2. If the velocity-time graph has the shape AMB, what would be the shape of the corresponding acceleration-time graph?



(a)


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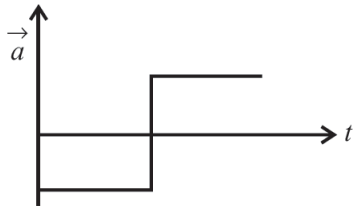

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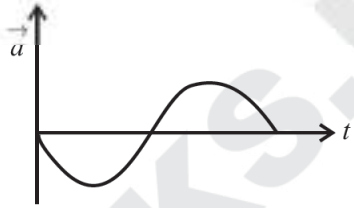

(d)

CHAPTER-4 : LAWS OF MOTION

3. The coefficient of static friction between a wooden block of mass 0.5 kg and a vertical rough wall is 0.2. The magnitude of horizontal force that should be applied on the block to keep it adhere to the wall will be _____ N.

[**g** = 10 ms^{-2}]

4. An inclined plane is bent in such a way that the vertical cross-section is given by $y = \frac{x^2}{4}$ where y is in vertical and x in horizontal direction. If the upper surface of this curved plane is rough with coefficient of friction $\mu = 0.5$, the maximum height in cm at which a stationary block will not slip downward is _____ cm.

CHAPTER-5 : WORK, ENERGY AND POWER

5. A ball with a speed of 9 m/s collides with another identical ball at rest. After the collision, the direction of each ball makes an angle of 30° with the original direction. The ratio of velocities of the balls after collision is $x : y$, where x is _____.

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CHAPTER-6 : ROTATIONAL MOTION

6. Moment of inertia (M.I.) of four bodies, having same mass and radius, are reported as;
I_1 = M.I. of thin circular ring about its diameter,
I_2 = M.I. of circular disc about an axis perpendicular to the disc and going through the centre,
I_3 = M.I. of solid cylinder about its axis and
I_4 = M.I. of solid sphere about its diameter.
Then :

(a) $I_1 + I_3 < I_2 + I_4$ (b) $I_1 + I_2 = I_3 + \frac{5}{2}I_4$

(c) $I_1 = I_2 = I_3 > I_4$ (d) $I_1 = I_2 = I_3 < I_4$

CHAPTER-7 : GRAVITATION

7. Two stars of masses m and $2m$ at a distance d rotate about their common centre of mass in free space. The period of revolution is :

(a) $\frac{1}{2\pi}\sqrt{\frac{d^3}{3Gm}}$ (b) $2\pi\sqrt{\frac{d^3}{3Gm}}$

(c) $\frac{1}{2\pi}\sqrt{\frac{3Gm}{d^3}}$ (d) $2\pi\sqrt{\frac{3Gm}{d^3}}$

8. Four identical particles of equal masses 1 kg made to move along the circumference of a circle of radius 1 m under the action of their own mutual gravitational attraction. The speed of each particle will be :

(a) $\sqrt{\frac{G}{2}(1+2\sqrt{2})}$ (b) $\sqrt{G(1+2\sqrt{2})}$

(c) $\sqrt{\frac{G}{2}(2\sqrt{2}-1)}$ (d) $\frac{\sqrt{(1+2\sqrt{2})G}}{2}$

9. Consider two satellites S_1 and S_2 with periods of revolution 1 hr. and 8hr. respectively revolving around a planet in circular orbits. The ratio of angular velocity of satellite S_1 to the angular velocity of satellites S_2 is :

(a) 8 : 1 (b) 1 : 4 (c) 2 : 1 (d) 1 : 8

CHAPTER-8 : MECHANICAL PROPERTIES OF SOLIDS

10. If Y, K and η are the values of Young's modulus, bulk modulus and modulus of rigidity of any material respectively. Choose the correct relation for these parameters.

(a) $Y = \frac{9K\eta}{3K-\eta}$ N/m^2

(b) $\eta = \frac{3YK}{9K+Y}$ N/m^2

(c) $Y = \frac{9K\eta}{2\eta+3K}$ N/m^2

(d) $K = \frac{Y\eta}{9\eta-3Y}$ N/m^2

CHAPTER-9 : MECHANICAL PROPERTIES OF FLUIDS

11. A hydraulic press can lift 100 kg when a mass 'm' is placed on the smaller piston. It can lift _____ kg when the diameter of the larger piston is increased by 4 times and that of the smaller piston is decreased by 4 times keeping the same mass 'm' on the smaller piston.

CHAPTER-10 : THERMAL PROPERTIES OF MATTER

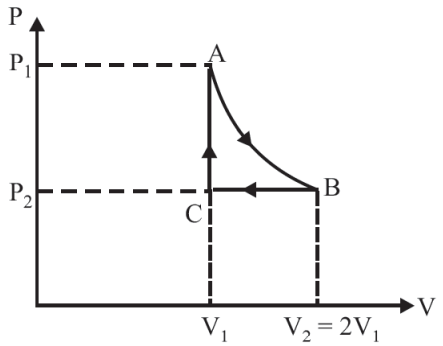
12. Each side of a box made of metal sheet in cubic shape is 'a' at room temperature 'T', the coefficient of linear expansion of the metal sheet is 'α'. The metal sheet is heated uniformly, by a small temperature ΔT, so that its new temperature is $T + \Delta T$. Calculate the increase in the volume of the metal box.

(a) $3a^3\alpha\Delta T$ (b) $4a^3\alpha\Delta T$

(c) $3\pi a^3\alpha\Delta T$ (d) $\frac{4}{3}\pi a^3\alpha\Delta T$

CHAPTER-11 : THERMODYNAMICS

13. n mole a perfect gas undergoes a cyclic process $ABCA$ (see (figure) consisting of the following processes.
A → B : Isothermal expansion at temperature T so that the volume is doubled from V_1 to $V_2 = 2V_1$ and pressure changes from P_1 to P_2.
B → C : Isobaric compression at pressure P_2 to initial volume V_1.
C → A : Isochoric change leading to change of pressure from P_2 to P_1.
Total work done in the complete cycle $ABCA$ is :



(a) 0 (b) $nRT\left(\ln 2+\frac{1}{2}\right)$

(c) $nRT\ln 2$ (d) $nRT\left(\ln 2-\frac{1}{2}\right)$

14. Match List-I with List-II:

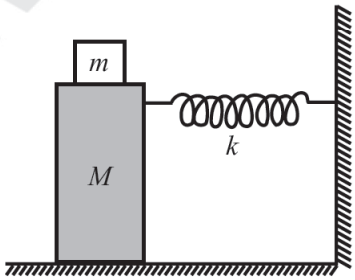
List-I	List-II
(A) Isothermal	(i) Pressure constant
(B) Isochoric	(ii) Temperature constant
(C) Adiabatic	(iii) Volume constant
(D) Isobaric	(iv) Heat content is constant

Choose the correct answer from the options given below:

(a) (A) → (i), (B) → (iii), (C) → (ii), (D) → (iv)
(b) (A) → (ii), (B) → (iii), (C) → (iv), (D) → (i)
(c) (A) → (ii), (B) → (iv), (C) → (iii), (D) → (i)
(d) (A) → (iii), (B) → (ii), (D) → (i), (D) → (iv)

CHAPTER-13 : OSCILLATIONS

15. In the given figure, a mass M is attached to a horizontal spring which is fixed on one side to a rigid support. The spring constant of the spring is k. The mass oscillates on a frictionless surface with time period T and amplitude A. When the mass is in equilibrium position, as shown in the figure, another mass m is gently fixed upon it. The new amplitude of oscillation will be :

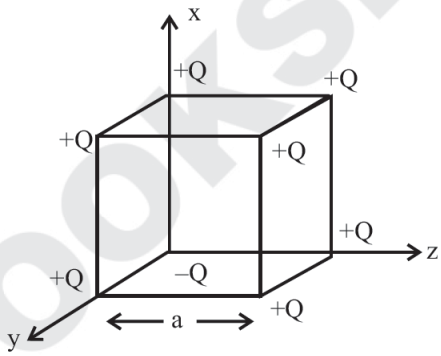


(a) $A\sqrt{\frac{M-m}{M}}$ (b) $A\sqrt{\frac{M}{M+m}}$

(c) $A\sqrt{\frac{M+m}{M}}$ (d) $A\sqrt{\frac{M}{M-m}}$

CHAPTER-15 : ELECTRIC CHARGES AND FIELDS

16. A cube of side 'a' has point charges + Q located at each of its vertices except at the origin where the charge is – Q. The electric field at the centre of cube is :



(a) $\frac{3Q}{3\sqrt{3}\pi\varepsilon_0 a^2}(\hat{x}+\hat{y}+\hat{z})$

(b) $\frac{-2Q}{3\sqrt{3}\pi\varepsilon_0 a^2}(\hat{x}+\hat{y}+\hat{z})$

(c) $\frac{2Q}{3\sqrt{3}\pi\varepsilon_0 a^2}(\hat{x}+\hat{y}+\hat{z})$

(d) $\frac{Q}{3\sqrt{3}\pi\varepsilon_0 a^2}(\hat{x}+\hat{y}+\hat{z})$

CHAPTER-16 : ELECTROSTATIC POTENTIAL AND CAPACITANCE

17. Two equal capacitors are first connected in series and then in parallel. The ratio of the equivalent capacities in the two cases will be :

(a) 4 : 1 (b) 2 : 1 (c) 1 : 4 (d) 1 : 2

CHAPTER-17 : CURRENT ELECTRICITY

18. A current through a wire depends on time as $i = \alpha_0 t + \beta t^2$ where $\alpha_0 = 20$ A/s and $\beta = 8$ As^{-2}. Find the charge crossed through a section of the wire in 15 s.

(a) 2250 C (b) 11250 C
(c) 2100 C (d) 260 C

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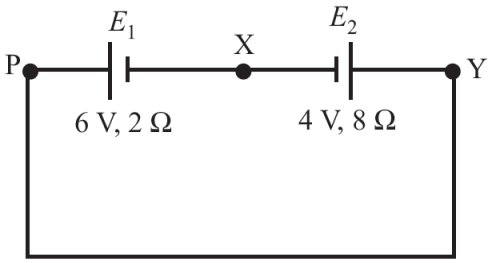
19. A cell E_1 of emf 6 V and internal resistance 2 Ω is connected with another cell E_2 of emf 4 V and internal resistance 8 Ω (as shown in the figure). The potential difference across points X and Y is :



(a) 10.0 V (b) 3.6 V
(c) 5.6 V (d) 2.0 V

CHAPTER-21 : ALTERNATING CURRENT

20. A resonance circuit having inductance and resistance 2×10^{-4} H and 6.28Ω respectively oscillates at 10 MHz frequency. The value of quality factor of this resonator is _____.
[π = 3.14]

21. A common transistor radio set requires 12 V (D.C.) for its operation. The D.C. source is constructed by using a transformer and a rectifier circuit, which are operated at 220 V (A.C.) on standard domestic A.C. supply. The number of turns of secondary coil are 24, then the number of turns of primary are _____.

CHAPTER-22 : ELECTROMAGNETIC WAVES

22. An electromagnetic wave of frequency 5 GHz, is travelling in a medium whose relative electric permittivity and relative magnetic permeability both are 2. Its velocity in this medium is _____ $\times 10^7$ m/s.

CHAPTER-23 : RAY OPTICS AND OPTICAL INSTRUMENTS

23. The focal length f is related to the radius of curvature r of the spherical convex mirror by :

(a) $f = +\frac{1}{2}r$ (b) $f = -r$

(c) $f = -\frac{1}{2}r$ (d) $f = r$

CHAPTER-24 : WAVE OPTICS

24. In a Young's double slit experiment, the width of the one of the slit is three times the other slit. The amplitude of the light coming from a slit is proportional to the slit-width. Find the ratio of the maximum to the minimum intensity in the interference pattern.
(a) 1 : 4 (b) 3 : 1 (c) 4 : 1 (d) 2 : 1

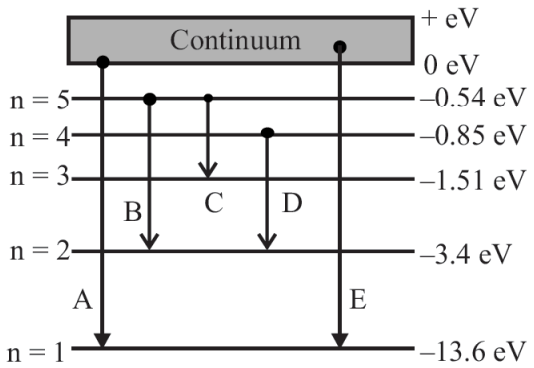
25. An unpolarized light beam is incident on the polarizer of a polarization experiment and the intensity of light beam emerging from the analyzer is measured as 100 Lumens. Now, if the analyzer is rotated around the horizontal axis (direction of light) by 30° in clockwise direction, the intensity of emerging light will be _____ Lumens.

CHAPTER-25 : DUAL NATURE OF RADIATION AND MATTER

26. Given below are two statements :
Statement-I : Two photons having equal linear momenta have equal wavelengths.
Statement-II: If the wavelength of photon is decreased, then the momentum and energy of a photon will also decrease.
In the light of the above statements, choose the correct answer from the options given below.
(a) Both Statement I and Statement II are true
(b) Statement I is false but Statement II is true
(c) Both Statement I and Statement II are false
(d) Statement I is true but Statement II is false

CHAPTER-26 : ATOMS

27. In the given figure, the energy levels of hydrogen atom have been shown along with some transitions marked A, B, C, D and E. The transitions A, B and C respectively represent :



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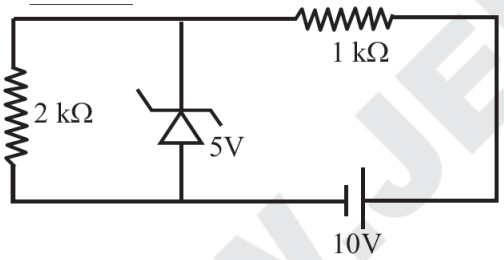
(a) The ionization potential of hydrogen, second member of Balmer series and third member of Paschen series.
(b) The first member of the Lyman series, third member of Balmer series and second member of Paschen series.
(c) The series limit of Lyman series, third member of Balmer series and second member of Paschen series.
(d) The series limit of Lyman series, second member of Balmer series and second member of Paschen series.

CHAPTER-28 : SEMICONDUCTOR ELECTRONICS :MATERIALS, DEVICES AND SIMPLE CIRCUITS

28. If an emitter current is changed by 4 mA, the collector current changes by 3.5 mA. The value of β will be :
(a) 7 (b) 0.5 (c) 0.875 (d) 3.5

29. In connection with the circuit drawn below, the value of current flowing through 2 kΩ resistor is _____ $\times 10^{-4}$ A.



CHAPTER-29 : COMMUNICATION SYSTEMS

30. An audio signal $v_m = 20 \sin 2\pi (1500\ t)$ amplitude modulates a carrier $v_c = 80 \sin 2\pi (100{,}000\ t)$.
The value of percent modulation is _____ .

CHEMISTRY

CHAPTER-1 : SOME BASIC CONCEPTS OF CHEMISTRY

31. 4.5 g of compound A (MW = 90) was used to make 250 mL of its aqueous solution. The molarity of the solution is M is $x \times 10^{-1}$. The value of x is _____ (Rounded off to the nearest integer)

CHAPTER-2 : STRUCTURE OF ATOM

32. A proton and a Li^{3+} nucleus are accelerated by the same potential. If λ_{Li} and λ_P denote the de Broglie wavelengths of Li^{3+} and proton respectively, then the value of $\frac{\lambda_{Li}}{\lambda_P}$ is $x \times 10^{-1}$. The value of x is _____
(Rounded off to the nearest integer)
(Mass of Li^{3+} = 8.3 mass of proton)

CHAPTER-3 : CLASSIFICATION OF ELEMENTS AND PERIODICITY IN PROPERTIES

33. Consider the elements Mg, Al, S, P and Si, the correct increasing order of their first ionization enthalpy is :
(a) Mg < Al < Si < S < P
(b) Al < Mg < Si < S < P
(c) Mg < Al < Si < P < S
(d) Al < Mg < S < Si < P

CHAPTER-4 : CHEMICAL BONDING AND MOLECULAR STRUCTURE

34. Which of the following are isostructural pairs?
A. SO_4^{2-} and CrO_4^{2-}
B. $SiCl_4$ and $TiCl_4$
C. NH_3 and NO_3^-
D. BCl_3 and $BrCl_3$
(a) C and D only (b) A and B only
(c) A and C only (d) B and C only

CHAPTER-7 : EQUILIBRIUM

35. At 1990 K and 1 atm pressure, there are equal number of Cl_2 molecules and Cl atoms in the reaction mixture. The value of K_P for the reaction $Cl_2(g) \rightleftharpoons 2Cl(g)$ under the above conditions is $x \times 10^{-1}$. The value of x is _____ (Rounded off to the nearest integer)

36. For the reaction $A(g) \rightarrow (B)(g)$, the value of the equilibrium constant at 300 K and 1 atm is equal to 100.0. The value of $\Delta_r G$ for the reaction at 300 K and 1 atm in J mol^{-1} is $-xR$, where x is _____ (Rounded off to the nearest integer)
(R = 8.31 J mol^{-1} K^{-1} and ln 10 = 2.3)

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CHAPTER-8 : REDOX REACTIONS

37. The reaction of sulphur in alkaline medium is given below:

$$S_8(s) + aOH^-(aq) \rightarrow bS^{2-}(aq) + cS_2O_3^{2-}(aq) + dH_2O(l)$$

The values of 'a' is _____. (Integer answer)

CHAPTER-9 : HYDROGEN

38. (A) $HOCl + H_2O_2 \rightarrow H_3O^+ + Cl^- + O_2$

(B) $I_2 + H_2O_2 + 2OH^- \rightarrow 2I^- + 2H_2O + O_2$

Choose the correct option.

(a) H_2O_2 acts as reducing and oxidising agent respectively in equation (A) and (B)
(b) H_2O_2 acts as oxidising agent in equation (A) and (B)
(c) H_2O_2 acts as reducing agent in equation (A) and (B)
(d) H_2O_2 act as oxidizing and reducing agent respectively in equation (A) and (B)

CHAPTER-10 : THE s-BLOCK ELEMENTS

39. Number of amphoteric compound among the following is _____

(A) BeO (B) BaO
(C) $Be(OH)_2$ (D) $Sr(OH)_2$

CHAPTER-11 : THE p-BLOCK ELEMENTS (GROUP-13 AND 14)

40. Al_2O_3 was leached with alkali to get X. The solution of X on passing of gas Y, forms Z. X, Y and Z respectively are:

(a) $X = Na[Al(OH)_4]$, $Y = SO_2$, $Z = Al_2O_3$
(b) $X = Na[Al(OH)_4]$, $Y = CO_2$, $Z = Al_2O_3 \cdot$
(c) $X = Al(OH)_3$, $Y = CO_2$, $Z = Al_2O_3$
(d) $X = Al(OH)_3$, $Y = SO_2$, $Z = Al_2O_3 \cdot H_2O$

41. Given below are two statements :

Statement I : Colourless cupric metaborate is reduced to cuprous metaborate in a luminous flame.

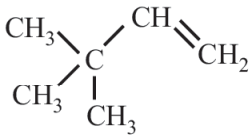
Statement II : Cuprous metaborate is obtained by heating boric anhydride and copper sulphate in a non-luminous flame.

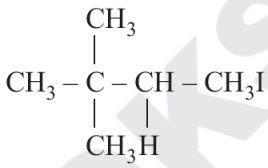
In the light of the above statements, choose the most appropriate answer from the options given below :

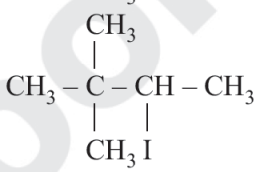
(a) Statement I is true but Statement II is false
(b) Both Statement I and Statement II are false
(c) Statement I is false but Statement II is true
(d) Both Statement I and Statement II are true

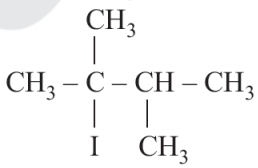
CHAPTER-13 : HYDROCARBONS

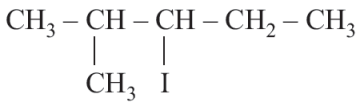
42. What is the major product formed by HI on reaction with



(a) 

(b) 

(c) 

(d) 

43. Which of the following reagent is used for the following reaction?

$$CH_3CH_2CH_3 \xrightarrow{?} CH_3CH_2CHO$$

(a) Manganese acetate
(b) Copper at high temperature and pressure
(c) Molybdenum oxide
(d) Potassium permanganate

CHAPTER-14 : ENVIRONMENTAL CHEMISTRY

44. The gas released during anaerobic degradation of vegetation may lead to:

(a) Ozone hole
(b) Acid rain
(c) Corrosion of metals
(d) Global warming and cancer

CHAPTER-15 : THE SOLID STATE

45. The coordination number of an atom in a body-centered cubic structure is _____.

[Assume that the lattice is made up of atoms.]

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CHAPTER-16 : SOLUTIONS

46. When 9.45 g of $ClCH_2COOH$ is added to 500 mL of water, its freezing point drops by 0.5°C. The dissociation constant of $ClCH_2COOH$ is $x \times 10^{-3}$. The value of x is _____. (Rounded off to the nearest integer)

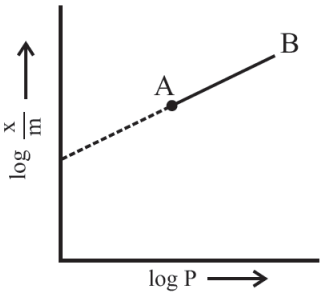
$[K_{f(H_2O)} = 1.86 \text{ K kg mol}^{-1}]$

CHAPTER-18 : CHEMICAL KINETICS

47. Gaseous cyclobutene isomerizes to butadiene in a first order process which has a 'k' value of 3.3×10^{-4} s^{-1} at 153 °C. The time in minutes it takes for the isomerization to proceed 40% to completion at this temperature is _____. (Rounded off to the nearest integer)

CHAPTER-19 : SURFACE CHEMISTRY

48. In Freundlich adsorption isotherm, slope of AB line is:



(a) log n with ($n > 1$)
(b) n with (n, 0.1 to 0.5)
(c) $\log\frac{1}{n}$ with ($n < 1$)
(d) $\frac{1}{n}$ with $\left(\frac{1}{n} = 0 \text{ to } 1\right)$

CHAPTER-20 : GENERAL PRINCIPLES AND PROCESSES OF ISOLATION OF ELEMENTS

49. Which of the following ore is concentrated using group 1 cyanide salt?
(a) Sphalerite (b) Calamine
(c) Siderite (d) Malachite

CHAPTER-22 : THE d-AND f-BLOCK ELEMENTS

50. The major components in "Gun Metal" are :
(a) Cu, Zn and Ni
(b) Cu, Sn and Zn
(c) Al, Cu, Mg and Mn
(d) Cu, Ni and Fe

51. The electrode potential of M^{2+}/M of 3d-series elements shows positive value of
(a) Zn (b) Fe (c) Co (d) Cu

CHAPTER-23 : CO-ORDINATION COMPOUNDS

52. The stepwise formation of $[Cu(NH_3)_4]^{2+}$ is given below

$$Cu^{2+} + NH_3 \xrightleftharpoons{K_1} [Cu(NH_3)_2]^{2+}$$

$$[Cu(NH_3)]^{2+} + NH_3 \xrightleftharpoons{K_2} [Cu(NH_3)_2]^{2+}$$

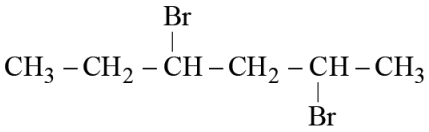
$$[Cu(NH_3)_2]^{2+} + NH_3 \xrightleftharpoons{K_3} [Cu(NH_3)_3]^{2+}$$

$$[Cu(NH_3)_3]^{2+} + NH_3 \xrightleftharpoons{K_4} [Cu(NH_3)_4]^{2+}$$

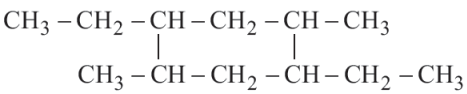
The value of stability constants K_1, K_2, K_3 and K_4 are 10^4, 1.58×10^3, 5×10^2 and 10^2 respectively. The overall equilibrium constants for dissociation of $[Cu(NH_3)_4]^{2+}$ is $x \times 10^{-12}$. The value of x is _____ (Rounded off to the nearest integer)

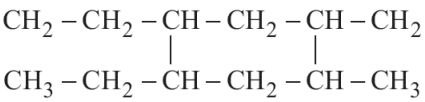
CHAPTER-24 : HALOALKANES AND HALOARENES

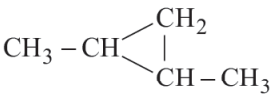
53. The product formed in the first step of the reaction of

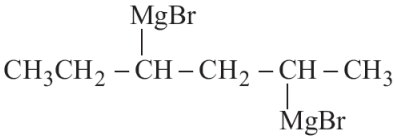


with excess $Mg/Et_2O(Et = C_2H_5)$ is :

(a) 

(b) 

(c) 

(d) 

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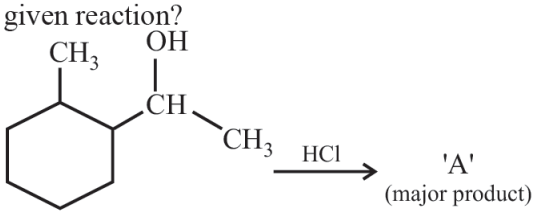
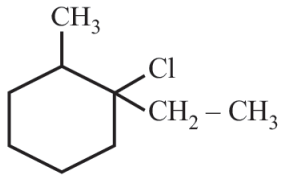
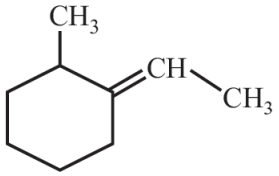
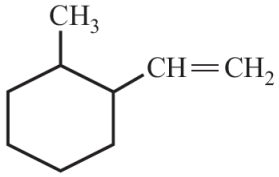
CHAPTER-25 : ALCOHOLS, PHENOLS AND ETHERS

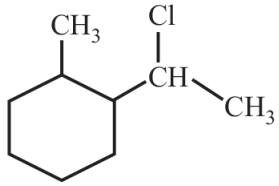
54. What is the final product (major) 'A' in the given reaction?



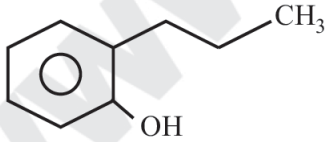
(a) 

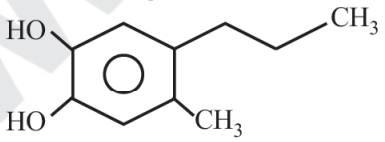
(b) 

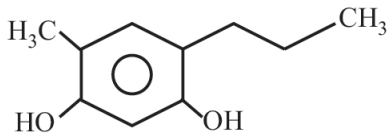
(c) 

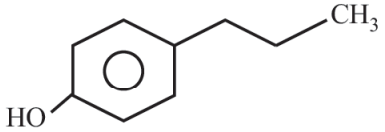
(d) 

55. Which of the following compound gives pink colour on reaction with phthalic anhydride in conc. H_2SO_4 followed by treatment with NaOH?

(a) 

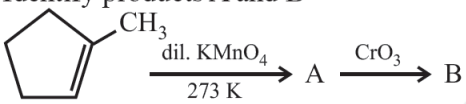
(b) 

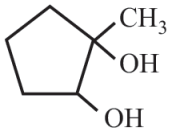
(c) 

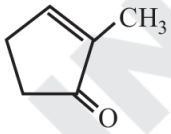
(d) 

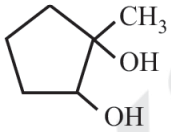
CHAPTER-26 : ALDEHYDES, KETONES AND CARBOXYLIC ACIDS

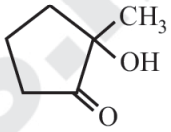
56. Identify products A and B



(a) A : 

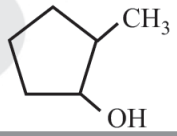
B : 

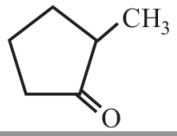
(b) A : 

B : 

(c) A : $OHC-CH_2CH_2CH_2-\overset{\overset{\large O}{\|}}{C}-CH_3$

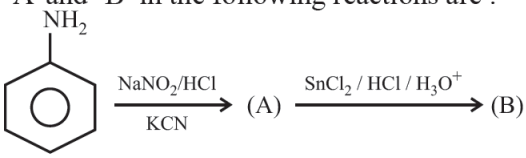
B : $HOOC-CH_2CH_2CH_2-\overset{\overset{\large O}{\|}}{C}-CH_3$

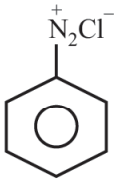
(d) A : 

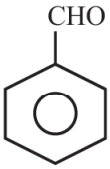
B : 

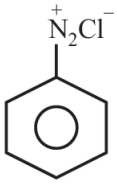
CHAPTER-27 : AMINES

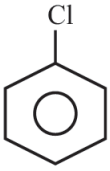
57. 'A' and 'B' in the following reactions are :

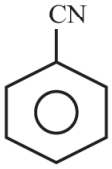


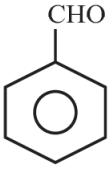
(a) (A) : 

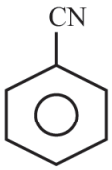
(B) : 

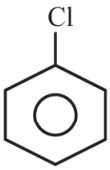
(b) (A) : 

(B) : 

(c) (A) : 

(B) : 

(d) (A) : 

(B) : 

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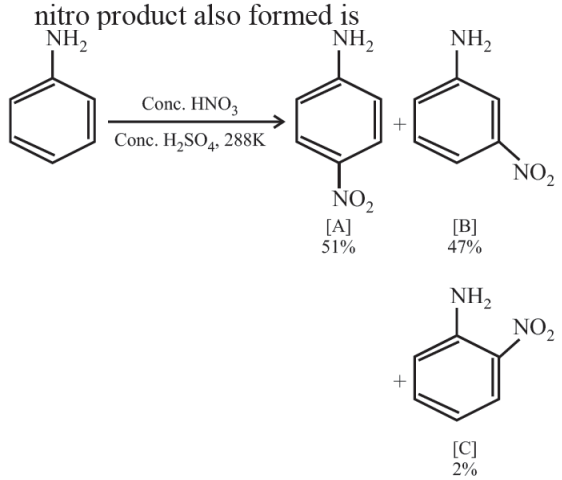
58. In the following reaction the reason why meta-nitro product also formed is



(a) low temperature
(b) $-NH_2$ group is highly meta-directive
(c) Formation of anilinium ion
(d) $-NO_2$ substitution always takes place at meta-position

CHAPTER-28 : BIOMOLECULES

59. Out of the following, which type of interaction is responsible for the stabilisation of α-helix structure of proteins?
(a) Ionic bonding
(b) Hydrogen bonding
(c) Covalent bonding
(d) vander Waals forces

CHAPTER-29 : POLYMERS

60. Match List-I with List-II.

List-I (Monomer Unit)	List-II (Polymer)
(A) Caprolactum	(i) Natural rubber
(B) 2-Chloro-1, 3-butadiene	(ii) Buna-N
(C) Isoperene	(iii) Nylon 6
(D) Acrylonitrile	(iv) Neoprene

Choose the correct answer from the options given below:
(a) (A)-(iv), (B)-(iii), (C)-(ii), (D)-(i)
(b) (A)-(ii), (B)-(i), (C)-(iv), (D)-(iii)
(c) (A)-(iii), (B)-(iv), (C)-(i), (D)-(ii)
(d) (A)-(i), (B)-(ii), (C)-(iii), (D)-(iv)

MATHEMATICS

CHAPTER-5 : COMPLEX NUMBERS AND QUADRATIC EQUATIONS

61. Let p and q be two positive numbers such that $p + q = 2$ and $p^4 + q^4 = 272$. Then p and q are roots of the equation:
(a) $x^2 - 2x + 2 = 0$ (b) $x^2 - 2x + 8 = 0$
(c) $x^2 - 2x + 136 = 0$ (d) $x^2 - 2x + 16 = 0$

62. If the least and the largest real values of α, for which the equation $z + \alpha|z - 1| + 2i = 0$ ($z \in C$ and $i = \sqrt{-1}$) has a solution, are p and q respectively, then $4(p^2 + q^2)$ is equal to _____.

CHAPTER-7 : PERMUTATIONS AND COMBINATIONS

63. A scientific committee is to be formed from 6 Indians and 8 foreigners, which includes at least 2 Indians and double the number of foreigners as Indians. Then the number of ways, the committee can be formed, is :
(a) 1625 (b) 575 (c) 560 (d) 1050

CHAPTER-8 : BINOMIAL THEOREM

64. The value of $-{}^{15}C_1 + 2.{}^{15}C_2 - 3.{}^{15}C_3 + ... -15.{}^{15}C_{15} + {}^{14}C_1 + {}^{14}C_3 + {}^{14}C_5 + ... + {}^{14}C_{11}$ is :
(a) $2^{16} - 1$ (b) $2^{13} - 14$
(c) 2^{14} (d) $2^{13} - 13$

CHAPTER-9 : SEQUENCE AND SERIES

65. If $e^{(\cos^2 x + \cos^4 x + \cos^6 x + ... \infty)\log_e 2}$ satisfies the equation $t^2 - 9t + 8 = 0$, then the value of $\frac{2\sin x}{\sin x + \sqrt{3}\cos x}\left(0 < x < \frac{\pi}{2}\right)$ is
(a) $2\sqrt{3}$ (b) $\frac{3}{2}$ (c) $\sqrt{3}$ (d) $\frac{1}{2}$

66. Let $A = \{x : x$ is 3-digit number]
$B = \{x : x = 9k + 2, k \in I\}$
and $C = \{x : x = 9k + \ell, k \in I, \ell \in I, O < \ell < 9\}$ for some ℓ $(0 < \ell < 9)$
If the sum of all the elements of the set $A \cap (B \cup C)$ is 274×400, then ℓ is equal to _____.

CHAPTER-10 : STRAIGHT LINES & PAIR OF STRAIGHT LINES

67. A man is walking on a straight line. The arithmetic mean of the reciprocals of the intercepts of this line on the coordinate axes is $\frac{1}{4}$. Three stones A, B and C are placed at the points (1, 1), (2, 2) and (4, 4) respectively. Then which of these stones is/are on the path of the man?
(a) A only (b) C only
(c) All the three (d) B only

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CHAPTER-11 : CONIC SECTIONS

68. The locus of the mid-point of the line segment joining the focus of the parabola $y^2 = 4ax$ to a moving point of the parabola, is another parabola whose directrix is :

(a) $x = -\frac{a}{2}$ (b) $x = \frac{a}{2}$

(c) $x = 0$ (d) $x = a$

69. If one of the diameters of the circle $x^2 + y^2 - 2x - 6y + 6 = 0$ is a chord of another circle 'C', whose center is at (2, 1), then its radius is _____.

CHAPTER-12 : LIMITS AND DERIVATIVES

70. $\lim_{n\to\infty} \tan\left\{\sum_{r=1}^{n} \tan^{-1}\left(\frac{1}{1+r+r^2}\right)\right\}$ is equal to _____.

CHAPTER-13 : MATHEMATICAL REASONING

71. The statement among the following that is a tautology is:

(a) $A \vee (A \wedge B)$

(b) $A \wedge (A \vee B)$

(c) $B \to [A \wedge (A \to B)]$

(d) $[A \wedge (A \to B)] \to B$

CHAPTER-16 : RELATIONS AND FUNCTIONS

72. Let $f : R \to R$ be defined as $f(x) = 2x - 1$ and $g : R - \{1\} \to R$ be defined as $g(x) = \frac{x - \frac{1}{2}}{x-1}$.

Then the composition function $f(g(x))$ is :

(a) onto but not one-one

(b) both one-one and onto

(c) one-one but not onto

(d) neither one-one nor onto

CHAPTER-18 : MATRICES

73. Let M be any 3×3 matrix with entries from the set $\{0, 1, 2\}$. The maximum number of such matrices, for which the sum of diagonal elements of M^TM is seven, is _____.

CHAPTER-19 : DETERMINANTS

74. The system of linear equations :

$3x - 2y - kz = 10$; $2x - 4y - 2z = 6$; $x + 2y - z = 5m$

is inconsistent if :

(a) $k = 3, m = \frac{4}{5}$ (b) $k \neq 3, m \in R$

(c) $k \neq 3, m \neq \frac{4}{5}$ (d) $k = 3, m \neq \frac{4}{5}$

75. Let $P = \begin{bmatrix} 3 & -1 & -2 \\ 2 & 0 & \alpha \\ 3 & -5 & 0 \end{bmatrix}$, where $\alpha \in R$. Suppose $Q = [q_{ij}]$ is a matrix satisfying $PQ = kI_3$ for some non-zero $k \in R$. If $q_{23} = -\frac{k}{8}$ and $|Q| = \frac{k^2}{2}$, then $\alpha^2 + k^2$ is equal to _____.

CHAPTER-20 : CONTINUITY AND DIFFERENTIABILITY

76. If $f : R \to R$ is a function defined by $f(x) = [x - 1] \cos\left(\frac{2x-1}{2}\right)\pi$, where [.] denotes the greatest integer function, then f is:

(a) discontinuous at all integral values of x except at $x = 1$

(b) continuous only at $x = 1$

(c) continuous for every real x

(d) discontinuous only at $x = 1$

CHAPTER-21 : APPLICATION OF DERIVATIVES

77. If the tangent to the curve $y = x^3$ at the point $P(t, t^3)$ meets the curve again at Q, then the ordinate of the point which divides PQ internally in the ratio 1 : 2 is :

(a) $-2t^3$ (b) 0 (c) $-t^3$ (d) $2t^3$

78. The function

$f(x) = \frac{4x^3 - 3x^2}{6} - 2\sin x + (2x-1)\cos x$:

(a) increases in $\left[\frac{1}{2}, \infty\right)$

(b) increases in $\left(-\infty, \frac{1}{2}\right]$

(c) decreases in $\left[\frac{1}{2}, \infty\right)$

(d) decreases in $\left(-\infty, \frac{1}{2}\right]$

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79. The minimum value of α for which the equation $\frac{4}{\sin x}+\frac{1}{1-\sin x}=\alpha$ has at least one solution in $\left(0,\frac{\pi}{2}\right)$ is _____.

CHAPTER-22 : INTEGRALS

80. If $\int\frac{\cos x-\sin x}{\sqrt{8-\sin 2x}}dx = a\sin^{-1}\left(\frac{\sin x+\cos x}{b}\right)+c,$ where c is a constant of integration, then the ordered pair (a, b) is equal to

(a) $(-1, 3)$ (b) $(3, 1)$
(c) $(1, 3)$ (d) $(1, -3)$

81. $\lim\limits_{x\to 0}\frac{\int_0^{x^2}(\sin\sqrt{t})\,dt}{x^3}$ is equal to :

(a) $\frac{2}{3}$ (b) $\frac{3}{2}$ (c) 0 (d) $\frac{1}{15}$

82. If $\int_{-a}^{a}(|x|+|x-2|)\,dx = 22$, $(a > 2)$ and $[x]$ denotes the greatest integer $\le x$, then $\int_{a}^{-a}(x+[x])\,dx$ is equal to _____ .

CHAPTER-23 : APPLICATIONS OF INTEGRALS

83. The area (in sq. units) of the part of the circle $x^2 + y^2 = 36$, which is outside the parabola $y^2 = 9x$, is :

(a) $24\pi+3\sqrt{3}$ (b) $12\pi-3\sqrt{3}$
(c) $24\pi-3\sqrt{3}$ (d) $12\pi+3\sqrt{3}$

CHAPTER-24 : DIFFERENTIAL EQUATIONS

84. The population $P = P(t)$ at time 't' of a certain species follows the differential equation $\frac{dP}{dt} = 0.5\,P - 450$. If $P(0) = 850$, then the time at which population becomes zero is :

(a) $\log_e 18$ (b) $\log_e 9$
(c) $\frac{1}{2}\log_e 18$ (d) $2\log_e 18$

CHAPTER-25 : VECTOR ALGEBRA

85. Let three vectors $\vec{a},\vec{b}$ and $\vec{c}$ be such that $\vec{c}$ is coplanar with $\vec{a}$ and $\vec{b}$, $\vec{a}.\vec{c}=7$ and $\vec{b}$ is perpendicular to $\vec{c}$, where $\vec{a}=-\hat{i}+\hat{j}+\hat{k}$ and $\vec{b}=2\hat{i}+\hat{k}$, then the value of $2|\vec{a}+\vec{b}+\vec{c}|^2$ is _____.

CHAPTER-26 : THREE DIMENSIONAL GEOMETRY

86. The equation of the plane passing through the point (1, 2, –3) and perpendicular to the planes $3x + y - 2z = 5$ and $2x - 5y - z = 7$, is

(a) $3x - 10y - 2z + 11 - 0$
(b) $6x - 5y - 2z - 2 = 0$
(c) $11x + y + 17z + 38 = 0$
(d) $6x - 5y + 2z + 10 = 0$

87. The distance of the point (1, 1, 9) from the point of intersection of the line $\frac{x-3}{1}=\frac{y-4}{2}=\frac{z-5}{2}$ and the plane x + y + z = 17 is :

(a) $2\sqrt{19}$ (b) $19\sqrt{2}$ (c) 38 (d) $\sqrt{38}$

CHAPTER-27 : PROBABILITY

88. An ordinary dice is rolled for a certain number of times. If the probability of getting an odd number 2 times is equal to the probability of getting an even number 3 times, then the probability of getting an odd number for odd number of times is :

(a) $\frac{1}{32}$ (b) $\frac{5}{16}$ (c) $\frac{3}{16}$ (d) $\frac{1}{2}$

89. Let B_i $(i = 1, 2, 3)$ be three independent events in a sample space. The probability that only B_1 occur is α. Only B_2 occurs is β and only B_3 occurs is γ. Let p be the probability that none of the events B_i occurs and these 4 probabilities satisfy the equations $(\alpha - 2\beta)\,p = \alpha\beta$ and $(\beta - 3\gamma)\,p = 2\beta\gamma$ (All the probabilities are assumed to lie in the interval (0, 1)). Then $\frac{P(B_1)}{P(B_3)}$ is equal to _____.

CHAPTER-28 : PROPERTIES OF TRIANGLES

90. Two vertical poles are 150 m apart and the height of one is three times that of the other. If from the middle point of the line joining their feet, an observer finds the angles of elevation of their tops to be complementary, then the height of the shorter pole (in meters) is :

(a) $20\sqrt{3}$ (b) $25\sqrt{3}$ (c) 30 (d) 25

ANSWER KEY

1	(b)	**11**	(25600)	**21**	(440)	**31**	(2)	**41**	(b)	**51**	(d)	**61**	(d)	**71**	(d)	**81**	(a)
2	(b)	**12**	(a)	**22**	(15)	**32**	(2)	**42**	(c)	**52**	(1)	**62**	(10)	**72**	(c)	**82**	(3)
3	(25)	**13**	(d)	**23**	(a)	**33**	(b)	**43**	(c)	**53**	(d)	**63**	(a)	**73**	(540)	**83**	(c)
4	(25)	**14**	(b)	**24**	(c)	**34**	(b)	**44**	(d)	**54**	(a)	**64**	(b)	**74**	(d)	**84**	(d)
5	(1)	**15**	(b)	**25**	(75)	**35**	(5)	**45**	(8)	**55**	(a)	**65**	(d)	**75**	(17)	**85**	(75)
6	(c)	**16**	(b)	**26**	(d)	**36**	(1380)	**46**	(35)	**56**	(b)	**66**	(5)	**76**	(c)	**86**	(c)
7	(b)	**17**	(c)	**27**	(c)	**37**	(12)	**47**	(26)	**57**	(b)	**67**	(d)	**77**	(a)	**87**	(d)
8	(d)	**18**	(b)	**28**	(a)	**38**	(c)	**48**	(d)	**58**	(c)	**68**	(c)	**78**	(a)	**88**	(d)
9	(a)	**19**	(c)	**29**	(25)	**39**	(2)	**49**	(a)	**59**	(b)	**69**	(3)	**79**	(9)	**89**	(6)
10	(d)	**20**	(2000)	**30**	(25)	**40**	(b)	**50**	(b)	**60**	(c)	**70**	(1)	**80**	(c)	**90**	(b)

Hints and Solutions

PHYSICS

1. **(b)** $\dfrac{x^2}{\alpha kT} \rightarrow$ dimensionless

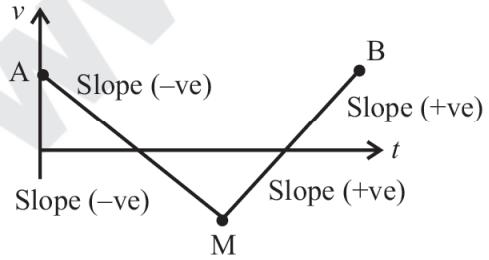
$$\Rightarrow [\alpha] = \frac{[x^2]}{[kT]} = \frac{L^2}{ML^2T^{-2}} = M^{-1}T^2$$

Now, $[W] = [\alpha]\,[\beta]^2$

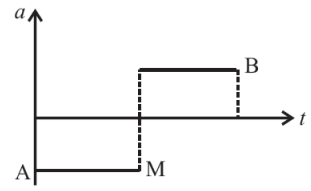
$$[\beta]^2 = \frac{[W]}{[\alpha]}$$

$$[\beta] = \left(\frac{ML^2T^{-2}}{M^{-1}T^2}\right)^{\frac{1}{2}} = MLT^{-2}$$

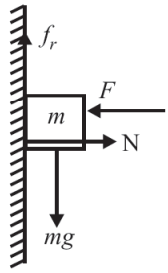
2. **(b)** Slope of v-t graph gives acceleration



As slope is negative from A to M. So, acceleration is negative and constant from A to M. From M to B, slope is positive and hence acceleration. So, correct graph will be as follow



3. **(25)** F.B.D. of the block is shown in the diagram



Since, block is at rest,

$\therefore f_r - mg = 0$ ... (i)

$F - N = 0$ ... (ii)

$f_r \;\; \mu N$

In limiting case,

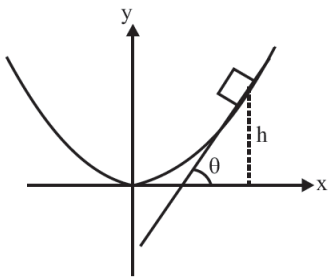
$f_r = \mu N = \mu F$ ... (iii)

Using equation (i) and (iii),

$$F = \frac{mg}{\mu}$$

$$\Rightarrow F = \frac{0.5 \times 10}{0.2} = 25\,N$$

4. **(25)**

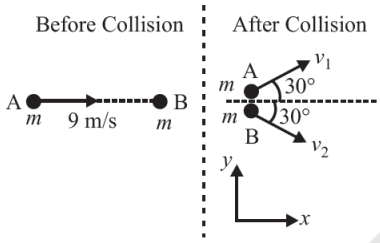


Block will experience maximum force due to friction when it is at maximum height, h at this height, if slope of the tangent is tan θ, then θ = Angle of repose.

$$\therefore \tan\theta = \frac{dy}{dx} = \frac{d}{dk}\left(\frac{x^2}{4}\right) = \frac{x}{2} = 0.5$$

$\Rightarrow x = 1$ and therefore $y = 0.25$ m = 25 cm (Assuming that x & y in the equation are given in meter)

5. **(1)**



From conservation of momentum along y-axis.

$$\vec{P}_{iy} = \vec{P}_{fy}$$

$$0 + 0 = mv_1 \sin 30^\circ\, \hat{j} + mv_2 \sin 30^\circ(-\hat{j})$$

$$mv_2 \sin 30^\circ = mv_1 \sin 30^\circ$$

$$v_2 = v_1 \text{ or } \frac{v_1}{v_2} = 1$$

6. **(c)** Moment of inertia of ring about its diameter,

$$I_1 = \frac{MR^2}{2}$$

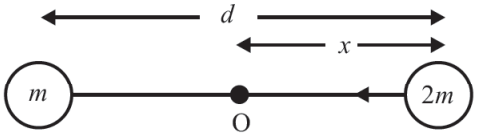
Moment of inertia of disc, $I_2 = \dfrac{MR^2}{2}$

Moment of inertia of solid cylinder, $I_3 = \dfrac{MR^2}{2}$

Moment of inertia of solid sphere, $I_4 = \dfrac{2}{5}MR^2$

$$\therefore I_1 = I_2 = I_3 > I_4$$

7. **(b)**



For point O to be the centre of mass of the system, moment about O should be zero.

$$\therefore 2mx = m(d - x)$$

$$\Rightarrow 3mx = md$$

$$\Rightarrow x = \frac{d}{3}$$

For equilibrium,

$$F_{\text{gravitational}} = F_{\text{centripetal}}$$

$$\therefore F = \frac{G(2m)m}{d^2} = (2m)\omega^2\left(\frac{d}{3}\right)$$

$$\Rightarrow \frac{Gm}{d^2} = \omega^2\frac{d}{3}$$

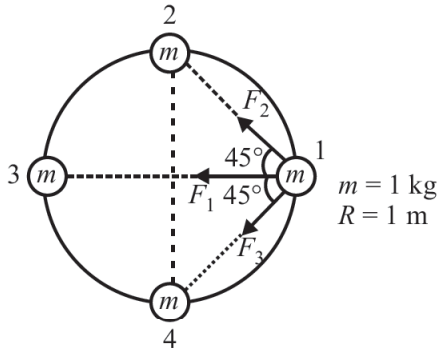
$$\Rightarrow \omega^2 = \frac{3Gm}{d^3}$$

$$\Rightarrow \omega = \sqrt{\frac{3Gm}{d^3}}$$

∴ Period of revolution,

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{d^3}{3Gm}}$$

8. **(d)**



Gravitational force acting between particle 1 and 3 is

$$F_1 = \frac{Gmm}{(2R)^2} = \frac{Gm^2}{4R^2}$$

Gravitational force acting between particle 1 and 2 is

$$F_2 = \frac{Gmm}{(\sqrt{2}R)^2} = \frac{Gm^2}{2R^2}$$

Gravitational force acting between 1 and 4 is

$$F_3 = \frac{Gmm}{(\sqrt{2}R)^2} = \frac{Gm^2}{2R^2}$$

Net force towards the centre,

$$F_{\text{net}} = F_1 + F_2\cos 45^\circ + F_3\cos 45^\circ$$

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$$= \frac{Gm^2}{4R^2} + \frac{Gm^2}{2R^2}\frac{1}{\sqrt{2}} + \frac{Gm^2}{2R^2}\frac{1}{\sqrt{2}}$$

$$= \frac{Gm^2}{R^2}\left(\frac{1}{4} + \frac{1}{2\sqrt{2}} + \frac{1}{2\sqrt{2}}\right)$$

$$= \frac{Gm^2}{R^2}\left(\frac{1}{4} + \frac{1}{\sqrt{2}}\right) = \frac{Gm^2}{4R^2}\left(1 + 2\sqrt{2}\right)$$

At equilibrium $F_{\text{centre}} = F_{\text{centripetal}}$

$$F_{\text{net}} = \frac{Gm^2}{4R^2}(1 + 2\sqrt{2}) = \frac{mv^2}{R}$$

$$\Rightarrow v = \sqrt{\frac{(2\sqrt{2}+1)Gm}{4R}}$$

Put $m = 1$ kg, $R = 1$ m, we get

$$\Rightarrow v = \frac{\sqrt{G(1+2\sqrt{2})}}{2}$$

9. **(a)** Ratio $\frac{T_1}{T_2} = \frac{1}{8}$

$$\frac{\frac{2\pi}{\omega_1}}{\frac{2\pi}{\omega_2}} = \frac{1}{8} \qquad \left(\because T = \frac{2\pi}{\omega}\right)$$

$$\frac{\omega_1}{\omega_2} = \frac{8}{1}$$

10. **(d)** We know that

$Y = 3K(1 - 2\sigma)$

Here,

σ = Poisson's ratio

$$\sigma = \frac{1}{2}\left(1 - \frac{Y}{3K}\right) \qquad ...(i)$$

Also,

$Y = 2\eta(1 + \sigma)$

$$\sigma = \frac{Y}{2\eta} - 1 \qquad ...(ii)$$

From equation (i) and (ii), we have

$$\frac{1}{2}\left(1 - \frac{Y}{3K}\right) = \frac{Y}{2\eta} - 1$$

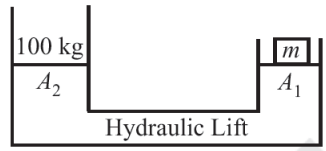
$$\Rightarrow 1 - \frac{Y}{3K} = \frac{Y}{\eta} - 2 \Rightarrow \frac{Y}{3K} = 3 - \frac{Y}{\eta}$$

$$\Rightarrow \frac{Y}{} \quad \frac{\eta - Y}{}$$

$$\Rightarrow \frac{\eta Y}{3K} = 3\eta - Y$$

$$\Rightarrow K = \frac{\eta Y}{9\eta - 3Y}$$

11. **(25600)** Using Pascal's law,



$$\frac{100 \times g}{A_2} = \frac{mg}{A_1}(A_1 < A_2) \qquad ...(i)$$

Let m mass can lift M_0 in second case then

$$\frac{M_0 g}{16A_2} = \frac{mg}{\frac{A_1}{16}} \qquad \left(\because A = \frac{\pi d^2}{4}\right) \qquad ...(ii)$$

From equation (i) and (ii), we get

$$\frac{M_0}{16 \times 100} = 16$$

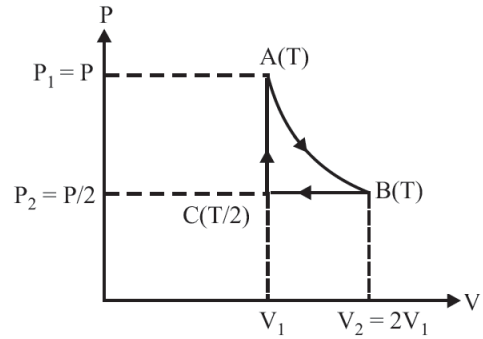
$M_0 = 25600$ kg

12. **(a)** $\Delta V = V\gamma\Delta T$

Since, $V = a^3$ and $\gamma = 3\alpha$

$\therefore \Delta V = 3a^3\alpha\Delta T$

13. **(d)**



Work done during isothermal process,

$$W_{AB} = nRT\ln\left(\frac{V_2}{V_1}\right)$$

$$W_{AB} = nRT\ln\left(\frac{2V}{V}\right) = nRT\ln 2$$

$$W_{BC} = nR(T_C - T_B) = nR\left(\frac{T}{2} - T\right) = -nR\frac{T}{2}$$

$W_{CA} = P\Delta V = 0 \qquad (\because \Delta V = 0)$

$\Rightarrow W_{\text{net}} = W_{AB} + W_{BC} + W_{CA}$

$$\Rightarrow W_{\text{net}} = nRT\ln 2 - \frac{nRT}{2}$$

$$\Rightarrow W_{\text{net}} = nRT\left(\ln 2 - \frac{1}{2}\right)$$

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14. **(b)** (A) Isothermal ($\Delta T = 0$)

(A) → (ii)

(B) Isochoric ($\Delta V = 0$)

(B) → (iii)

(C) Adiabatic ($\Delta Q = 0$)

(C) → (iv)

(D) Isobaric ($\Delta P = 0$)

(D) → (i)

15. **(b)** Let the initial velocity of M is V.

On putting m on M, let velocity becomes V'.

Momentum of system remains conserved.

$\therefore p_i = p_f$

$\Rightarrow MV = (m + M)V'$

$\Rightarrow MA\omega = (m + M)A\omega \ (\because V = A\omega)$

$$\Rightarrow MA\sqrt{\frac{k}{M}} = (m+M)A'\sqrt{\frac{k}{m+M}}$$

$$\left(\because k = M\omega^2 \quad \Rightarrow \omega = \sqrt{\frac{k}{M}}\right)$$

$$\Rightarrow A' = A\sqrt{\frac{M}{M+m}}$$

16. **(b)** Electric field due to all charges will cancel out except two charges $+Q$ and $-Q$ placed along body diagonal.

$$\vec{E}_{-Q} = \frac{-Q}{4\pi\varepsilon_0 \frac{3a^2}{4}} \frac{(\hat{x}+\hat{y}+\hat{z})}{\sqrt{3}}$$

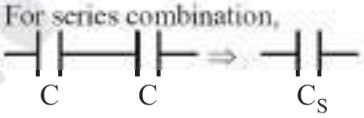
$$\vec{E}_{+Q} = \frac{-Q}{3\pi\varepsilon_0 a^2} \frac{(\hat{x}+\hat{y}+\hat{z})}{\sqrt{3}}$$

Net electric field at the centre of cube is

$$\vec{E}_{net} = \vec{E}_{-Q} + \vec{E}_{+Q}$$

$$= \frac{-2Q}{3\sqrt{3}\pi\varepsilon_0 a^2}(\hat{x}+\hat{y}+\hat{z})$$

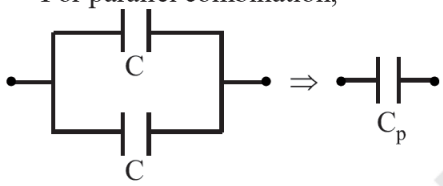
17. **(c)** For series combination,



$$\frac{1}{C_S} = \frac{1}{C} + \frac{1}{C}$$

$$\Rightarrow \boxed{C_S = \frac{C}{2}}$$

For parallel combination,



$C_p = C + C$

$\Rightarrow C_p = 2C$

$$\Rightarrow \frac{C_S}{C_p} = \frac{\left(\frac{C}{2}\right)}{2C} = \frac{1}{4} = 1:4$$

18. **(b)** Given, $i = \alpha_0 t + \beta t^2$

Put $\alpha_0 = 20$ and $\beta = 8$

We get $i = 20t + 8t^2$

Current, $i = \dfrac{dq}{dt}$

$$\Rightarrow \int dq = \int i dt$$

$$\Rightarrow q = \int_0^{15} (20t + 8t^2)dt$$

$$\Rightarrow q = \left(\frac{20t^2}{2} + \frac{8t^3}{3}\right)_0^{15}$$

$$\Rightarrow q = 20 \times \left(\frac{15^2 - 0^2}{2}\right) + \frac{8}{3}(15^3 - 0^3)$$

$$\Rightarrow q = 10 \times (15)^2 + \frac{8(15)^3}{3}$$

$\Rightarrow q = 2250 + 9000$

$\Rightarrow q = 11250$ C

19. **(c)** $I = \dfrac{6-4}{10} = \dfrac{1}{5}$ A

$$V_x + 4 + 8 \times \frac{1}{5} - V_y = 0$$

$V_x - V_y = -5.6$

$\Rightarrow |V_x - V_y| = 5.6$ V

20. **(2000)** Given : $L = 2 \times 10^{-4}$ H

$R = 6.28\ \Omega$

$\nu = 10$ MHz $= 10^7$ Hz

Since, quality factor,

$$Q = \omega_0 \frac{L}{R} = 2\pi\nu \frac{L}{R}$$

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$$\therefore Q = 2\pi \times 10^7 \times \frac{2\times10^{-4}}{6.28}$$

$Q = 2 \times 10^3 = 2000$

21. **(440)** As we know,

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

Since, $N_S = 24$, $V_P = 220$ V and $V_S = 12$ V

$$\frac{N_P}{24} = \frac{220}{12}$$

$$N_P = \frac{220\times24}{12} = 440$$

22. **(15)** Given : Frequency of wave $\nu = 5$ GHz $= 5 \times 10^9$ Hz

Relative permittivity of the medium, $\varepsilon_r = 2$ and relative permeability of the medium, $\mu_r = 2$

Since speed of light in a medium is given by,

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_r\mu_0\varepsilon_r\varepsilon_0}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$$

where c is speed of light is vacuum.

$$\therefore v = \frac{3\times10^8}{\sqrt{4}} = \frac{30\times10^7}{2}\text{m/s} = 15 \times 10^7 \text{ m/s}$$

23. **(a)** For convex mirror, focus is behind the mirror. So, its focal length (f) is positive.

$$\therefore \quad f = +\frac{r}{2}$$

24. **(c)** Let the amplitude of light wave coming from the narrower slit be A_1 and amplitude of light wave from the wider slit be A_2.

As amplitude $\propto$ Width of slit

$\therefore A_2 = 3A_1$

Maximum intensity occurs where constructive interference takes place and the minimum intensity where destructive interference takes place.

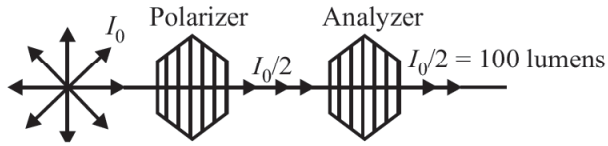
$\therefore A_{max} = 3A_1 + A_1 = 4A_1$

and $A_{min} = 3A_1 - A_1 = 2A_1$

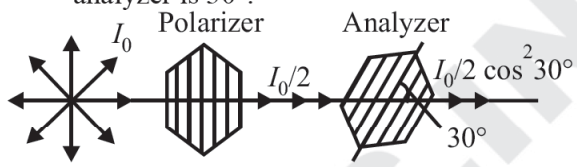
$\because$ Intensity $I \propto A^2$

$$\therefore \frac{I_{max}}{I_{min}} = \frac{A^2_{max}}{A^2_{min}} = \left(\frac{4A_1}{2A_1}\right)^2 = 4 : 1$$

25. **(75)** Assuming initially axis of polarizer and analyzer are parallel



When the angle between axis of polarizer and analyzer is 30°.



Now emerging intensity $= \frac{I_0}{2}\cos^2 30°$

$$= 100\left(\frac{\sqrt{3}}{2}\right)^2 = 100\times\frac{3}{4} = 75$$

26. **(d)** Momentum of photon,

$$p = \frac{h}{\lambda}$$

Here, h = Plank's constant,

λ = wavelength og light

Energy of photon $E = \frac{hc}{\lambda}$

If linear momentum are equal then wavelength also equal.

On decreasing wavelength, momentum and energy of photon increases.

27. **(c)** A corresponds to transition from $n = \infty$ to $n = 1$.

It is a series limit of Lymen series.

B corresponds to transition from $n = 5$ to $n = 2$.

It is a third member of Balmer series.

C corresponds to transition from $n = 5$ to $n = 3$, thus, it is second member of Paschen series.

28. **(a)** Given,

$\Delta I_e = 4$mA

$\Delta I_c = 3.5$ mA

For transistors,

$I_e = I_C + I_B$

$\therefore \Delta I_e = \Delta I_C + \Delta I_B$

$\Rightarrow 4mA = 3.5mA + \Delta I_B \Rightarrow \Delta I_B = 0.5mA$

Current gain for common emitter transistor,

$$\beta = \frac{\Delta I_C}{\Delta I_B} \Rightarrow \beta = \frac{3.5}{0.5}$$

$\Rightarrow \beta = 7$

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29. **(25)** Current through 2 kΩ resistance is

$$I = \frac{5}{2\times10^3} = 2.5\times10^{-3}\text{ A}$$

$$I = 25\times10^{-4}\text{ A}$$

30. **(25)** % modulation $= \frac{A_m}{A_c}\times100$

$$= \frac{20}{80}\times100 = 25\%$$

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31. **(2)** $M = \frac{4.5/90}{250/1000} = 0.2 = 2\times10^{-1}.$

32. **(2)** $\lambda = \frac{h}{\sqrt{2mqV}}$

$$\frac{\lambda_{Li}}{\lambda_P} = \sqrt{\frac{m_P(e)V}{m_{Li}(3e)(V)}} \qquad m_{Li} = 8.3m_P$$

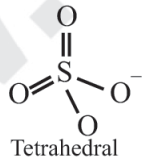
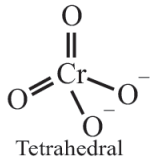
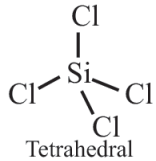
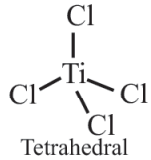
$$\frac{\lambda_{Li}}{\lambda_P} = \sqrt{\frac{1}{8.3\times3}} = \frac{1}{5} = 0.2 = 2\times10^{-1}$$

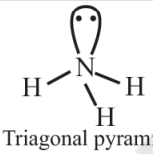
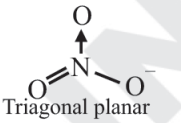
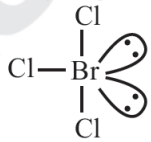
33. **(b)** Mg and P exhibit abnormal behaviour. Due to extra stability of half-filled and full-filled electronic configuration.

First ionisation enthalpy order is

Al < Mg < Si < S < P

34. **(b)** Isostructural means same structure.

Species	Structure
(A) SO_4^{2-}	 Tetrahedral
CrO_4^{2-}	 Tetrahedral
(B) $SiCl_4$	 Tetrahedral
$TiCl_4$	 Tetrahedral

Species	Structure
(C) NH_3	 Triagonal pyramidal
NO_3^-	 Triagonal planar
(D) BCl_3	Triagonal planar
$BrCl_3$	 T-shape

35. **(5)** $Cl_2(g) \rightleftharpoons 2Cl(g)$

Let mol of both of Cl_2 and Cl be x.

$$P_{Cl} = \frac{x}{2x}\times1 = \frac{1}{2}$$

$$P_{Cl_2} = \frac{x}{2x}\times1 = \frac{1}{2}$$

$$\therefore K_p = \frac{\left(\frac{1}{2}\right)^2}{\frac{1}{2}} = \frac{1}{2} = 0.5 = 5\times10^{-1}.$$

36. **(1380)** $\Delta G^\circ = RT\ln K_p$

$$= -R(300)(2)\ln(10)$$

$$= -R(300\times2\times2.3)$$

$$\Delta G^\circ = -1380R.$$

37. **(12)** $16e^- + S_8^- \longrightarrow 8S^{2-}$

$$12H_2O + S_8 \longrightarrow 4S_2O_3^{2-} + 24H^+ + 16e^-$$

$$2S_8 + 12H_2O \longrightarrow 8S^{2-} + 4S_2O_3^{2-} + 24H^+$$

For balancing in basic medium add OH^- equal to H^+.

$$2S_8 + 12H_2O + 24OH^- \longrightarrow 8S^{2-} + 4S_2O_8^{2-} + 24H_2O$$

$$2S_8 + 24OH^- \longrightarrow 8S^{2-} + 4S_2O_8^{2-} + 12H_2O$$

$$S_8 + 12OH^- \longrightarrow 4S^{2-} + 2S_2O_8^{2-} + 6H_2O$$

$$\therefore a = 12.$$

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38. (c)

(A) $HOCl + H_3O_2 \rightarrow H_3O^+ + Cl^- + O_2$

In this equation, H_2O_2 is reducing chlorine from +1 to –1.

(B) $I_2 + H_2O_2 + 2OH^- \rightarrow 2I^- + 2H_2O + O_2$

In this equation, H_2O_2 is reducing iodine from 0 to –1.

Therefore, in both the reactions H_2O_2 acts as a reducing agent.

39. (2) BeO and $Be(OH)_2$ are amphoteric in nature while BaO and $Sr(OH)_2$ are basic in nature.

40. (b) $Al_2O_3(s) + 2NaOH(aq.) + 3H_2O(l)$

$$\longrightarrow \underset{(X)}{2Na[Al(OH)_4](aq)} \xrightarrow[(Y)]{CO_2}$$

$$Al_2O_3 \cdot xH_2O(s) + 2NaHCO_3(aq.)$$

41. (b)

(I) Blue cupric metaborate $[Cu(BO_2)_2]$ is reduced to colourless cuprous metaborate $[Cu(BO_2)_2]$ in a luminous flame.

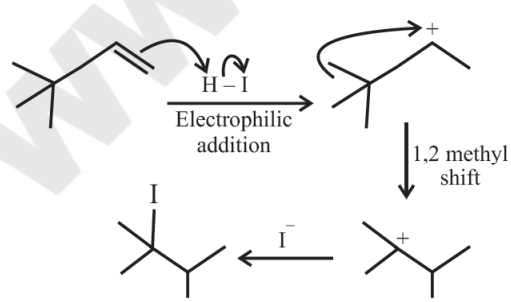
$$2Cu(BO_2)_2 + 2NaBO_2 + C \xrightarrow{\text{Luminous flame}}$$

$$2CuBO_2 + Na_2B_4O_7 + CO$$

(II) Cupric metaborate is obatined heating boric anhydride (B_2O_3) and copper sulphate in a non luminous flame.

$$B_2O_3 + CuSO_4 \xrightarrow[\text{flame}]{\text{Non-luminous}} \underset{\substack{\text{Cupric metaborate}\\ \text{(Blue-green)}}}{Cu(BO_2)_2} + SO_3$$

42. (c)



43. (c)

$$CH_3 - CH_2 - CH_3 \xrightarrow{MO_2O_3} CH_3 - CH_2 - CHO$$

44. (d) The gas, CH_4 evolved due to anaerobic degradation of vegetation which causes global warming and cancer.

45. (8)

46. (35) $ClCH_2COOH \rightleftharpoons ClCH_2COO^- + H^+$

Total dissociated = 1+ α

$\Rightarrow i = 1 + \alpha$

$\Delta T_f = ik_1m$

$$\Rightarrow 0.5 = (1+\alpha)(1.86) \times \frac{9.45}{94.5} \times \frac{1000}{500}$$

$\Rightarrow 0.5 = (1+\alpha)(1.86)\ (0.2)$

$\Rightarrow 1 + \alpha = 1.34 \Rightarrow \alpha = 0.34$

$ClCH_2COOH \rightleftharpoons ClCH_2COO^- + H^+$

At $t = 0$	α	0	0
At time t	$C - C\alpha$	$C\alpha$	$C\alpha$

$$K_a = \frac{(C\alpha)^2}{C - C\alpha} = \frac{C\alpha^2}{1-\alpha}$$

$$\Rightarrow K_a = \frac{0.2 \times (0.34)^2}{1 - 0.34} = 0.035$$

$\therefore K_a = 35 \times 10^{-3}$.

47. (26) $k = \frac{1}{t} \cdot \ln \frac{[A]_0}{[A]_t}$

$$\Rightarrow t = \frac{1}{k} \ln\left(\frac{100}{60}\right) \Rightarrow t = \frac{1}{3.3 \times 10^{-4}}$$

$\Rightarrow t = 1548.49$ sec

$\Rightarrow t = 25.81$ min ≈ 26 min.

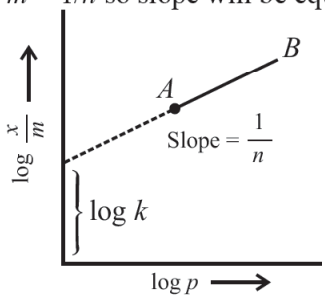
48. (d) Freundlich adsorption isotherm

$$\frac{x}{m} = kp^{1/n}$$

Taking logarithm

$$\log\left(\frac{x}{m}\right) = \log k + \frac{1}{n}\log p \Rightarrow y = c + mx$$

$m = 1/n$ so slope will be equal to $1/n$.



$\frac{1}{n}$ can have value between 0 and 1.

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49. **(a)** Sphalerite ore : ZnS
Calamine ore : $ZnCO_3$
Siderite ore : $FeCO_3$
Malachite ore : $Cu(OH)_2.CuCO_3$
In the froth flotation process (concentrated method), depressant helps to separates two sulphide ores by selective preventation of froth formation by one ore and allowing the other to come into froth.
For example, in case of an ore containing ZnS and PbS, NaCN is used as a depressant.
NaCN reacts with ZnS to form $Na_2[Zn(CN)_4]$, so it prevents ZnS from coming to the froth but allow PbS to come with the froth.

50. **(b)** The major components in "Gun Metal" are
Cu : 87%; Zn : 3%; Sn : 10%.

51. **(d)** Only copper shows positive value for electrode potential of M^{2+}/M of 3*d*-series elements.

52. **(1)**

$$Cu^{2+} + NH_3 \overset{K_1}{\rightleftharpoons} [Cu(NH_3)]^{2+}$$

$$[Cu(NH_3)]^{2+} + NH_3 \overset{K_2}{\rightleftharpoons} [Cu(NH_3)_2]^{2+}$$

$$[Cu(NH_3)_2]^{2+} + NH_3 \overset{K_3}{\rightleftharpoons} [Cu(NH_3)_3]^{2+}$$

$$[Cu(NH_3)_3]^{2+} + NH_3 \overset{K_4}{\rightleftharpoons} [Cu(NH_3)_4]^{2+}$$

$$Cu^{2+} + 4NH_3 \overset{K}{\rightleftharpoons} [Cu(NH_3)_4]^{2+}$$

So, $K = K_1 \times K_2 \times K_3 \times K_4$

$= 10^4 \times 1.58 \times 10^3 \times 5 \times 10^2 \times 10^2$

$\therefore K = 7.9 \times 10^{11}$.

Where K = Equilibrium constant for formation of $[Cu(NH_3)_4]^{2+}$

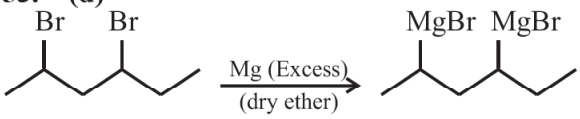
So, equilibrium constant (K') for dissociation of $[Cu(NH_3)_4]^{2+}$ is $\frac{1}{K}$

$$K' = \frac{1}{K}$$

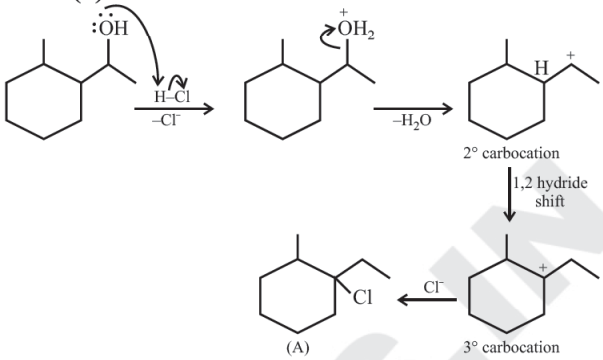
$$K' = \frac{1}{7.9 \times 10^{11}} = 1.26 \times 10^{-12} = (x \times 10^{-12})$$

So, $x = 1.26 \approx 1.0$.

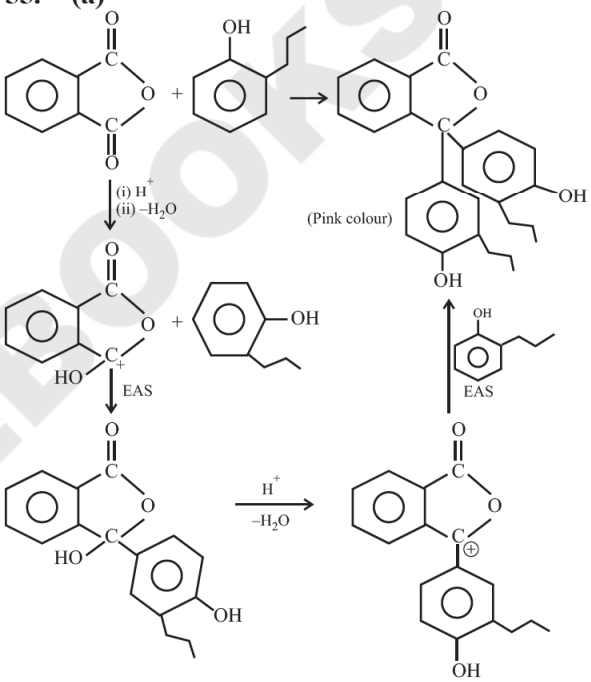
53. **(d)**



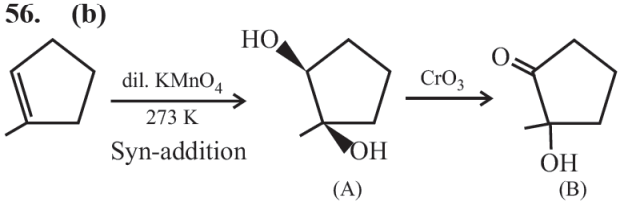
54. **(a)**



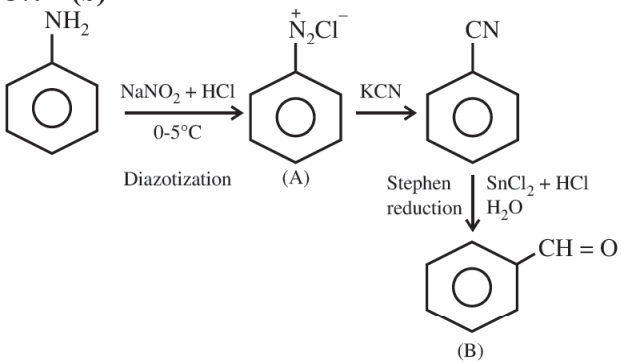
55. **(a)**



56. **(b)**



57. **(b)**



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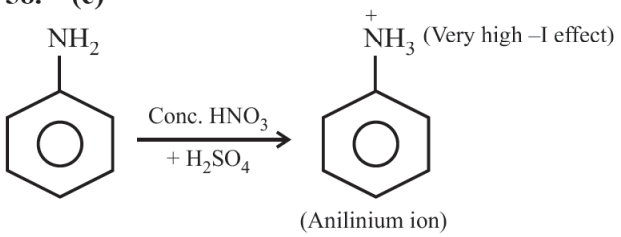
58. (c)

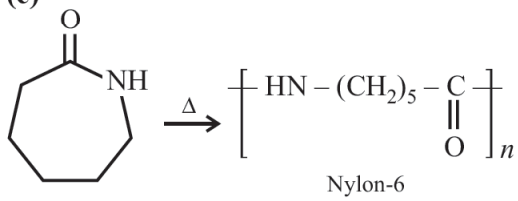


The positive anilinium nitrogen deactivates the benzene ring due to –I effect. It will behaves *m*-directing group as –I effect is more on -*o* and -*p* position and less on *m* position.
Therefore -*m* product is also formed along with -*o* and -*p* product.

59. (b) Hydrogen bonding is responsible for stabilisation of α-helix structure of proteins.

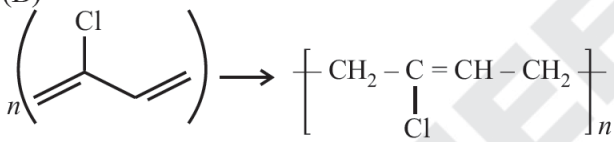
60. (c)

(A)



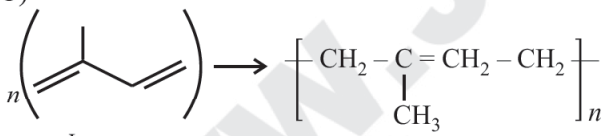
Nylon-6

(B)



2-chloro-1, 3-butadiene Neoprene (synthetic rubber)

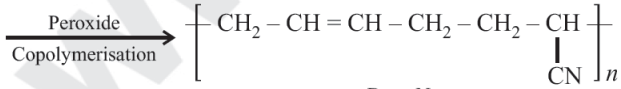
(C)



Isoprene (2-Methylbuta-1, 3-diene) Polyisoprene (Natural rubber)

(D) $nCH_2 = CH - CH = CH_2 + CH_2 = CH - CN$

1,3-Butadiene Aerylonitrile



Buna-N

MATHEMATICS

61. (d) We have $(p^2 + q^2)^2 - 2p^2q^2 = 272$

$((p + q)^2 - 2pq)^2 - 2p^2q^2 = 272$

$(4 - 2\,pq)^2 - 2p^2q^2 = 272$

$16 - 16pq + 2p^2q^2 = 272$

$(pq)^2 - 8pq - 128 = 0$

$pq = \dfrac{8 \pm 24}{2} = 16, -8$

$\therefore pq = 16 \quad (\because p, q > 0)$

$\therefore$ Required equation : $x^2 - (2)\,x + 16 = 0$

62. (10) Let $z = x + iy$

$x + iy + \alpha|x + iy - 1| + 2i = 0$

$\Rightarrow x + \alpha\sqrt{(x-1)^2 + y^2} + i(y+2) = 0 + 0i$

$\Rightarrow y + 2 = 0$ and $x + \alpha\sqrt{(x-1)^2 + y^2} = 0$

$\Rightarrow y = -2$ and $\alpha^2 = \dfrac{x^2}{x^2 - 2x + 5}$

Now, $\dfrac{x^2}{x^2 - 2x + 5} \in \left[0, \dfrac{5}{4}\right]$

$\therefore \alpha^2 \in \left[0, \dfrac{5}{4}\right] \Rightarrow \alpha \in \left[-\dfrac{\sqrt{5}}{2}, \dfrac{\sqrt{5}}{2}\right]$

$\therefore p = -\dfrac{\sqrt{5}}{2}; q = \dfrac{\sqrt{5}}{2}$

$\Rightarrow 4\,(p^2 + q^2) = 4\left(\dfrac{5}{4} + \dfrac{5}{4}\right) = 10$

63. (a)

Indians	Foreigners	Number of ways
2	4	${}^6C_2 \times {}^8C_4 = 1050$
3	6	${}^6C_3 \times {}^8C_6 = 560$
4	8	${}^6C_4 \times {}^8C_8 = 15$

Total number of ways = 1625

64. (b) $(-{}^{15}C_1 + 2.{}^{15}C_2 - 3.{}^{15}C_3 + ... - 15.{}^{15}C_{15})$
$+ ({}^{14}C_1 + {}^{14}C_3 + ... + {}^{14}C_{11})$

$= \sum_{r=1}^{15}(-1)^r\,.r\,{}^{15}C_r + ({}^{14}C_1 + {}^{14}C_3 + ...$
$+ {}^{14}C_{11} + {}^{14}C_{13}) - {}^{14}C_3$

$= \sum_{r=1}^{15}(-1)^r 15.\ {}^{14}C_{r-1} + 2^{13} - 14$

$= 15\,(-{}^{14}C_0 + {}^{14}C_1 ..... - {}^{14}C_{14}) + 2^{13} - 14$

$= 2^{13} - 14$

65. (d) $e^{(\cos^2 x + \cos^4 x + ...\infty)\ell n 2} = 2^{\cos^2 x + \cos^4 x + ...\infty} = 2^{\cot^2 x}$

Now $t^2 - 9t + 9 = 0 \Rightarrow t = 1, 8$

$\Rightarrow 2^{\cot^2 x} = 1, 8 \Rightarrow \cot^2 x = 0, 3$

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$$\Rightarrow \frac{2\sin x}{\sin x+\sqrt{3}\cos x}=\frac{2}{1+\sqrt{3}\cot x}=\frac{2}{4}=\frac{1}{2}$$

66. **(5)** B and C will contain three digit numbers of the form $9k + 2$ and $9k + \ell$ respectively. We need to find sum of all elements in the set $B \cup C$ effectively.

Now, $S(B \cup C) = S(B) + S(C) - S(B \cap C)$ where $S(k)$ denotes sum of elements of set k.

Also $B = \{101, 110, ...992\}$

$$\therefore S(B) = \frac{100}{2}(101+992) = 54650$$

Case-I : If $\ell = 2$

then $B \cap C = B$

$\therefore S(B \cup C) = S(B)$

which is not possible as given sum is $274 \times 400 = 109600$.

Case-II : If $\ell \neq 2$

then $B \cap C = \phi$

$\therefore S(B \cup C) = S(B) + S(C) = 400 \times 274$

$$\Rightarrow 54650 + \sum_{k=11}^{110} 9k+\ell = 109600$$

$$\Rightarrow 9\sum_{k=11}^{110} k + \sum_{k=11}^{110} \ell = 54950$$

$$\Rightarrow 9\left(\frac{100}{2}(11+110)\right)+\ell(100) = 54950$$

$\Rightarrow 54450 + 100\ell = 54950$

$\Rightarrow \ell = 5$

67. **(d)** Let the line be $y = mx + c$

$\therefore$ x-intercept : $-\frac{c}{m}$

y-intercept : c

A.M. of reciprocals of the intercepts :

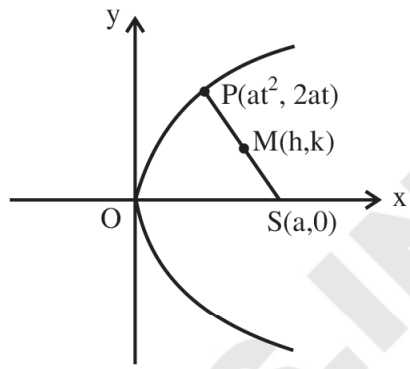
$$\frac{-\frac{m}{c}+\frac{1}{c}}{2} = \frac{1}{4} \Rightarrow 2(1-m) = c$$

Line : $y = mx + 2(1 - m) = c$

$\Rightarrow (y - 2) - m(x - 2) = 0$

$\Rightarrow$ line always passes through (2, 2)

68. **(c)**



$$h = \frac{at^2+a}{2}, k = \frac{2at+0}{2}$$

$$\Rightarrow t^2 = \frac{2h-a}{a} \text{ and } t = \frac{k}{a}$$

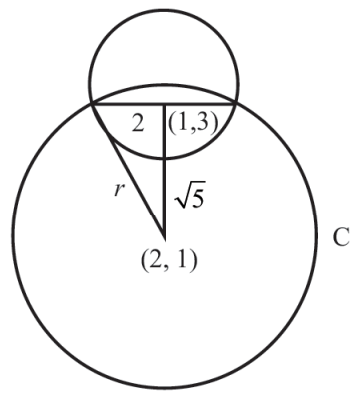
$$\Rightarrow \frac{k^2}{a^2} = \frac{2h-a}{a}$$

$\Rightarrow$ Locus of (h, k) is $y^2 = a(2x - a)$

$$\Rightarrow y^2 = 2a\left(x-\frac{a}{2}\right)$$

Its directrix is $x-\frac{a}{2} = -\frac{a}{2} \Rightarrow x = 0$

69. **(3)**



Given that $x^2 + y^2 - 2x - 6y + 6 = 0$

center (1, 3) and radius = 2

Distance between (1, 3) and (2, 1) is $\sqrt{5}$

$\therefore (\sqrt{5})^2 + (2)^2 = r^2$

$\Rightarrow r = 3$

70. **(1)** $$\lim_{n\to\infty} \tan\left(\sum_{r=1}^{n} \tan^{-1}\left(\frac{1}{1+r(r+1)}\right)\right)$$

$$= \lim_{n\to\infty} \tan\left(\sum_{r=1}^{n} \tan^{-1}\left(\frac{r+1-r}{1+r(r+1)}\right)\right)$$

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$$= \tan\left(\lim_{n\to\infty}\sum_{r=1}^{n}\left[\tan^{-1}(r+1)-\tan^{-1}(r)\right]\right)$$

$$= \tan\left(\lim_{n\to\infty}\left(\tan^{-1}(n+1)-\frac{\pi}{4}\right)\right)$$

$$= \tan\left(\frac{\pi}{4}\right)=1$$

71. **(d)** $(A \wedge (A \to B)) \to B$

$= (A \wedge (\sim A \vee B)) \to B$

$= ((A \wedge \sim A) \vee (A \wedge B)) \to B$

$= (A \wedge B) \to B$

$= \sim (A \wedge B) \vee B$

$= (\sim A \vee \sim B) \vee B$

$= T$

72. **(c)** $f(g(x)) = 2g(x) - 1 = 2\left(\frac{2x-1}{2(x-1)}\right)-1$

$$= \frac{x}{x-1} = 1+\frac{1}{x-1}$$

Range of $f(g(x)) = \mathbb{R} - \{1\}$

Range of $f(g(x))$ is not onto

& $f(g(x))$ is one-one

So, $f(g(x))$ is one-one but not onto.

73. **(540)** $\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}\begin{bmatrix} a & d & g \\ b & e & h \\ c & f & i \end{bmatrix}$

$a^2 + b^2 + c^2 + d^2 + e^2 + f^2 + g^2 + h^2 + i^2 = 7$

Case-I : Seven (1's) and two (0's)

$$\frac{9!}{7!2!} = 36$$

Case-II: One (2) and three (1's) and five (0's)

$$\frac{9!}{5!3!} = 504$$

$\therefore$ Total = 540

74. **(d)** $\Delta = \begin{vmatrix} 3 & -2 & -k \\ 2 & -4 & -2 \\ 1 & 2 & -1 \end{vmatrix} = 0$

$\Rightarrow 24 + 2(0) - k(8) = 0 \Rightarrow k = 3$

$$\Delta_x = \begin{vmatrix} 10 & -2 & -3 \\ 6 & -4 & -2 \\ 5m & 2 & -1 \end{vmatrix}$$

$= 10\,(8) - 2\,(-10m + 6) - 3(12 + 20m)$

$= 8(4 - 5m)$

$$\Delta_y = \begin{vmatrix} 3 & 10 & -3 \\ 2 & 6 & -2 \\ 1 & 5m & -1 \end{vmatrix}$$

$= 3\,(-6 + 10m) - 10(0) - 3(10m - 6)$

$= 0$

$$\Delta_z = \begin{vmatrix} 3 & -2 & 10 \\ 2 & -4 & 6 \\ 1 & 2 & 5m \end{vmatrix}$$

$= 3\,(-20m - 12) - 2\,(6 - 10m) + 10(8)$

$= -40m + 32 = 8\,(4 - 5m)$

For inconsistent,

$k = 3$ & $m \neq \frac{4}{5}$

75. **(17)** Given that

$PQ = kI$

$|P|.|Q| = k^3$

$\Rightarrow |P| = 2k\ \ 0 \Rightarrow P$ is an invertible matrix

$\because PQ = kI$

$\therefore Q = kP^{-1}I$ $\quad [\because P^{-1}P = I]$

$$\therefore Q = \frac{\text{adj.P}}{2}$$

$$\because q_{23} = -\frac{k}{8}$$

$$\therefore \frac{(3\alpha+4)}{2} = -\frac{k}{8} \Rightarrow k = 4$$

$\therefore |P| = 2k \Rightarrow k = 10 + 6\alpha$ ...(i)

Put value of k in (i)... we get $\alpha = -1$

$\therefore \alpha^2 + k^2 = 1 + 16 = 17.$

76. **(c)** For $x = n$, $n \in Z$

$$\text{LHL} = \lim_{x\to n^-} f(x) = \lim_{x\to n^-}[x-1]\cos\left(\frac{2x-1}{2}\right)\pi = 0$$

$$\text{RHL} = \lim_{x\to n^+} f(x) = \lim_{x\to n^+}[x-1]\cos\left(\frac{2x-1}{2}\right)\pi = 0$$

$f(n) = 0$

$\Rightarrow$ LHL = RHL = $f(n)$

$\Rightarrow f(x)$ is continuous for every real x.

77. **(a)** Slope of tangent at $P(t, t^3) = \left.\frac{dy}{dx}\right]_{(t,t^3)}$

$= (3x^2)^{x=t} = 3t^2$

So, equation tangent at $P(t, t^3)$:

$y - t^3 = 3t^2(x - t)$

For point of intersection with $y = x^3$

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$x^3 - t^3 = 3t^2x - 3t^3$

$\Rightarrow (x - t)(x^2 + xt + t^2) = 3t^2(x - t)$

For $x \neq t$

$x^2 + xt + t^2 = 3t^2$

$\Rightarrow x^2 + xt - 2t^2 = 0 \Rightarrow (x - t)(x + 2t) = 0$

So, for $Q : x = -2t$, $Q(-2t, -8t^3)$

ordinate of required point :

$$\frac{2t^3 - 8t^3}{2+1} = -2t^3$$

78. (a) Given that

$$f(x) = \frac{4x^3 - 3x^2}{6} - 2\sin x + (2x-1)\cos x$$

$f'(x) = (2x^2 - x) - 2\cos x + 2\cos x$

$- \sin x\,(2x - 1)$

$= (2x - 1)(x - \sin x)$

For $x > 0$, $x - \sin x > 0$

$x < 0$, $x - \sin x < 0$

For $x \in (-\infty, 0] \cup \left[\frac{1}{2}, \infty\right)$, $f'(x) \geq 0$

For $x \in \left[0, \frac{1}{2}\right]$, $f'(x) \leq 0$

$\Rightarrow f(x)$ increases in $\left[\frac{1}{2}, \infty\right)$.

79. (9) Let $f(x) = \frac{4}{\sin x} + \frac{1}{1 - \sin x}$

$\Rightarrow f'(x) = 0 \Rightarrow \sin x = 2/3$

$\therefore f(x)_{\min} = \frac{4}{2/3} + \frac{1}{1 - 2/3} = 9$

$f(x)_{\max.} \to \infty$

$f(x)$ is continuous function

$\therefore \alpha_{\min} = 9$

80. (c) $\int \frac{\cos x - \sin x}{\sqrt{8 - \sin 2x}}\,dx$

$$\int \frac{\cos x - \sin x}{\sqrt{9 - (\sin x + \cos x)^2}}\,dx$$

Let $\sin x + \cos x = t$

$$\int \frac{dt}{\sqrt{9 - t^2}} = \sin^{-1}\frac{t}{3} + c$$

$$= \sin^{-1}\left(\frac{\sin x + \cos x}{3}\right) + c$$

So $a = 1$, $b = 3$.

81. (a) $$\lim_{x \to 0^+} \frac{\int_0^{x^2} \sin\sqrt{t}\,dt}{x^3} = \lim_{x \to 0^+} \frac{(\sin x)2x}{3x^2}$$

$$= \lim_{x \to 0^+} \left(\frac{\sin x}{x}\right) \times \frac{2}{3} = \frac{2}{3}$$

82. (3) We have,

$$\int_{-a}^{0} (-2x + 2)\,dx + \int_0^2 (x + 2 - x)\,dx + \int_2^a (2x - 2)\,dx = 22$$

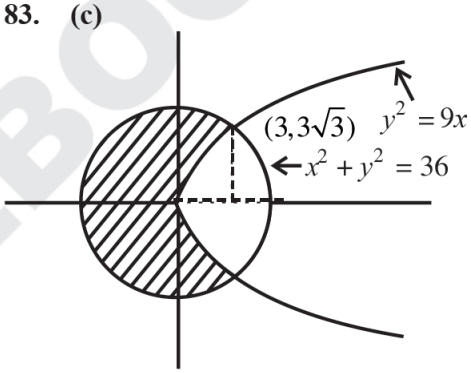
$\Rightarrow x^2 - 2x\,|_0^{-a} + 2x\,|_0^2 + x^2 - 2x\,|_2^a = 22$

$\Rightarrow a^2 + 2a + 4 + a^2 - 2a - (4 - 4) = 22$

$\Rightarrow 2a^2 = 18 \Rightarrow a = 3$

$$\therefore \int_3^{-3} (x + [x])dx = -(-3 - 2 - 1 + 1 + 2) = 3$$

83. (c)



Required area

$$= \pi \times (6)^2 - 2\int_0^3 \sqrt{9}x\,dx - 2\int_3^6 \sqrt{36 - x^2}\,dx$$

$$= 36\pi - 12\sqrt{3} - 2\left(\frac{x}{2}\sqrt{36 - x^2} + 18\sin^{-1}\frac{x}{6}\right)_3^6$$

$$= 36\pi - 12\sqrt{3} - 2\left(9\pi - 3\pi - \frac{9\sqrt{3}}{2}\right)$$

$$= 24\pi - 3\sqrt{3}$$

84. (d) Given that $\frac{dP}{dt} = 0.5P - 450$

$$\Rightarrow \int_0^t \frac{dp}{P - 900} = \int_0^t \frac{dt}{2}$$

$$\Rightarrow [\ell n\,|P(t) - 900|]_0^t = \left[\frac{t}{2}\right]_0^t$$

$$\Rightarrow \ell n\,|P(t) - 900| - \ell n\,|P(0) - 900| = \frac{t}{2}$$

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$\Rightarrow \ell n\,|P(t)-900|-\ell n\,|50| = \frac{t}{2}$

For $P(t) = 0$

$\Rightarrow \ell n\left|\frac{900}{50}\right| = \frac{t}{2}$

$\Rightarrow t = 2\ell n18$

85. (75) Let $\vec{c} = \lambda(\vec{b}\times(\vec{a}\times\vec{b}))$

$= \lambda((\vec{b}.\vec{b})\vec{a}-(\vec{b}.\vec{a})\vec{b})$

$= \lambda(5(-\hat{i}+\hat{j}+\hat{k})+2\hat{i}+\hat{k})$

$= \lambda(-3\hat{i}+5\hat{j}+6\hat{k})$

$\vec{c}.\vec{a} = 7 \Rightarrow 3\lambda+5\lambda+6\lambda = 7$

$\lambda = \frac{1}{2}$

$\therefore 2\left|\left(\frac{-3}{2}-1+2\right)\hat{i}+\left(\frac{5}{2}+1\right)\hat{j}+(3+1+1)\hat{k}\right|^2$

$= 2\left(\frac{1}{4}+\frac{49}{4}+25\right) = 25+50 = 75$

86. (c) Normal vector :

$$\begin{vmatrix} \hat{i} & j & \hat{k} \\ 3 & 1 & -2 \\ 2 & -5 & -1 \end{vmatrix} = -11\hat{i}-\hat{j}-17\hat{k}$$

So, direction ratios of normal to the required plane are < 11, 1, 17 >

Plane passes through (1, 2, – 3)

So, equation of plane :

$11(x-1)+1(y-2)+17(z+3) = 0$

$\Rightarrow 11x+y+17z+38 = 0$

87. (d) Let $\frac{x-3}{1} = \frac{y-4}{2} = \frac{z-5}{2} = t$

$\Rightarrow x = 3+t,\ y = 2t+4,\ z = 2t+5$

For point of intersection with $x+y+z = 17$

$3+t+2t+4+2t+5 = 17$

$\Rightarrow 5t = 5 \Rightarrow t = 1$

$\Rightarrow$ Point of intersection is (4, 6, 7)

Distance between (1, 1, 9) and (4, 6, 7) is

$\sqrt{(4-1)^2+(6-1)^2+(7-9)^2}$

$= \sqrt{9+25+4} = \sqrt{38}.$

88. (d) ${}^nC_2\left(\frac{1}{2}\right)^n = {}^nC_3\left(\frac{1}{2}\right)^n \Rightarrow {}^nC_2 = {}^nC_3$

$\Rightarrow n = 5$

Probability of getting an odd number for odd number of times is

${}^5C_1\left(\frac{1}{2}\right)^5+{}^5C_2\left(\frac{1}{2}\right)^5+{}^5C_3\left(\frac{1}{2}\right)^5$

$= \frac{1}{2^5}(5+10+1) = \frac{1}{2}$

89. (6) Let $P(B_1) = p_1$, $P(B_2) = p_2$, $P(B_3) = p_3$

given that $p_1(1-p_2)(1-p_3) = \alpha$ ... (i)

$p_2(1-p_1)(1-p_3) = \beta$ ... (ii)

$p_3(1-p_1)(1-p_2) = \gamma$ ... (iii)

and $(1-p_1)(1-p_2)(1-p_3) = p$ ... (iv)

$\Rightarrow \frac{p_1}{1-p_1} = \frac{\alpha}{p}, \frac{p_2}{1-p_2} = \frac{\beta}{p}\ \&\ \frac{p_3}{1-p_3} = \frac{\gamma}{p}$

Also $\beta = \frac{\alpha p}{\alpha+2p} = \frac{3\gamma p}{p-2\gamma}$

$\Rightarrow \alpha p - 2\alpha\gamma = 3\alpha\gamma + 6p\gamma$

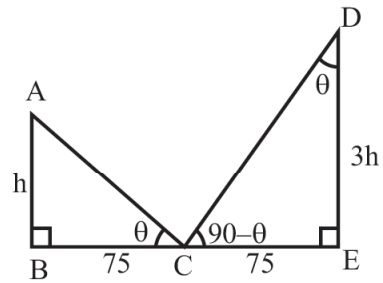
$\Rightarrow \alpha p - 6p\gamma - 5\alpha\gamma$

$\Rightarrow \frac{p_1}{1-p_1} - \frac{6p_3}{1-p_3} = \frac{5p_1p_3}{(1-p_1)(1-p_3)}$

$\Rightarrow p_1 - 6p_3 = 0$

$\Rightarrow \frac{p_1}{p_3} = 6$

90. (b)



In right angle ABC

and right ΔCDE

$\tan\theta = \frac{h}{75}$ and $\cot(90-\theta)$

$= \tan\theta = \frac{75}{3h}$

$\Rightarrow h^2 = \frac{(75)^2}{3}$

$h = 25\sqrt{3}$m

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PHYSICS

1 Physical World, Units and Measurements

1. Identify the pair whose dimensions are equal **[2002]**
(a) torque and work (b) stress and energy
(c) force and stress (d) force and work

2. Dimensions of $\frac{1}{\mu_0 \varepsilon_0}$, where symbols have their usual meaning, are **[2003]**
(a) $[L^{-1}T]$ (b) $[L^{-2}T^2]$
(c) $[L^2T^{-2}]$ (d) $[LT^{-1}]$

3. The physical quantities not having same dimensions are **[2003]**
(a) torque and work
(b) momentum and planck's constant
(c) stress and young's modulus
(d) speed and $(\mu_0\varepsilon_0)^{-1/2}$

4. Which one of the following represents the correct dimensions of the coefficient of viscosity? **[2004]**
(a) $[ML^{-1}T^{-1}]$ (b) $[MLT^{-1}]$
(c) $[ML^{-1}T^{-2}]$ (d) $[ML^{-2}T^{-2}]$

5. Out of the following pair, which one does NOT have identical dimensions? **[2005]**
(a) Impulse and momentum
(b) Angular momentum and planck's constant
(c) Work and torque
(d) Moment of inertia and moment of a force

6. The dimensions of magnetic field in M, L, T and C (coulomb) is given as **[2008]**
(a) $[MLT^{-1}C^{-1}]$ (b) $[MT^2C^{-2}]$
(c) $[MT^{-1}C^{-1}]$ (d) $[MT^{-2}C^{-1}]$

7. A body of mass m = 3.513 kg is moving along the x-axis with a speed of 5.00 ms^{-1}. The magnitude of its momentum is recorded as **[2008]**
(a) 17.6 kg ms^{-1} (b) 17.565 kg ms^{-1}
(c) 17.56 kg ms^{-1} (d) 17.57 kg ms^{-1}

8. Two full turns of the circular scale of a screw gauge cover a distance of 1mm on its main scale. The total number of divisions on the circular scale is 50. Further, it is found that the screw gauge has a zero error of – 0.03 mm. While measuring the diameter of a thin wire, a student notes the main scale reading of 3 mm and the number of circular scale divisions in line with the main scale as 35. The diameter of the wire is **[2008]**
(a) 3.32 mm (b) 3.73 mm
(c) 3.67 mm (d) 3.38 mm

9. In an experiment the angles are required to be measured using an instrument, 29 divisions of the main scale exactly coincide with the 30 divisions of the vernier scale. If the smallest division of the main scale is half- a degree (= 0.5°), then the least count of the instrument is: **[2009]**
(a) half minute (b) one degree
(c) half degree (d) one minute

10. The respective number of significant figures for the numbers 23.023, 0.0003 and 2.1×10^{-3} are **[2010]**
(a) 5, 1, 2 (b) 5, 1, 5
(c) 5, 5, 2 (d) 4, 4, 2

11. A screw gauge gives the following reading when used to measure the diameter of a wire.
Main scale reading : 0 mm
Circular scale reading : 52 divisions
Given that 1mm on main scale corresponds to 100 divisions of the circular scale. The diameter of wire from the above data is **[2011]**
(a) 0.052 cm (b) 0.026 cm
(c) 0.005 cm (d) 0.52 cm

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12. Resistance of a given wire is obtained by measuring the current flowing in it and the voltage difference applied across it. If the percentage errors in the measurement of the current and the voltage difference are 3% each, then error in the value of resistance of the wire is **[2012]**
(a) 6% (b) zero (c) 1% (d) 3%

13. A spectrometer gives the following reading when used to measure the angle of a prism.
Main scale reading : 58.5 degree
Vernier scale reading : 09 divisions
Given that 1 division on main scale corresponds to 0.5 degree. Total divisions on the Vernier scale is 30 and match with 29 divisions of the main scale. The angle of the prism from the above data is **[2012]**
(a) 58.59 degree (b) 58.77 degree
(c) 58.65 degree (d) 59 degree

14. Let $[\epsilon_0]$ denote the dimensional formula of the permittivity of vacuum. If M = mass, L = length, T = time and A = electric current, then: **[2013]**
(a) $\epsilon_0 = [M^{-1} L^{-3} T^2 A]$
(b) $\epsilon_0 = [M^{-1} L^{-3} T^4 A^2]$
(c) $\epsilon_0 = [M^1 L^2 T^1 A^2]$
(d) $\epsilon_0 = [M^1 L^2 T^1 A]$

15. The current voltage relation of a diode is given by $I = (e^{1000V/T} - 1)$mA, where the applied voltage V is in volts and the temperature T is in degree kelvin. If a student makes an error measuring ±0.01V while measuring the current of 5 mA at 300 K, what will be the error in the value of current in mA? **[2014]**
(a) 0.2 mA (b) 0.02 mA
(c) 0.5 mA (d) 0.05 mA

16. A student measured the length of a rod and wrote it as 3.50 cm. Which instrument did he use to measure it? **[2014]**
(a) A meter scale.
(b) A vernier calliper where the 10 divisions in vernier scale matches with 9 division in main scale and main scale has 10 divisions in 1 cm.
(c) A screw gauge having 100 divisions in the circular scale and pitch as 1 mm.
(d) A screw gauge having 50 divisions in the circular scale and pitch as 1 mm.

17. The period of oscillation of a simple pendulum is $T = 2\pi\sqrt{\frac{L}{g}}$. Measured value of L is 20.0 cm known to 1 mm accuracy and time for 100 oscillations of the pendulum is found to be 90 s using a wrist watch of 1s resolution. The accuracy in the determination of g is : **[2015]**
(a) 1% (b) 5% (c) 2% (d) 3%

18. A student measures the time period of 100 oscillations of a simple pendulum four times. The data set is 90 s, 91 s, 95 s, and 92 s. If the minimum division in the measuring clock is 1 s, then the reported mean time should be: **[2016]**
(a) 92 ± 1.8 s (b) 92 ± 3s
(c) 92 ± 1.5 s (d) 92 ± 5.0 s

19. A screw gauge with a pitch of 0.5 mm and a circular scale with 50 divisions is used to measure the thickness of a thin sheet of Aluminium. Before starting the measurement, it is found that wen the two jaws of the screw gauge are brought in contact, the 45th division coincides with the main scale line and the zero of the main scale is barely visible. What is the thickness of the sheet if the main scale reading is 0.5 mm and the 25th division coincides with the main scale line? **[2016]**
(a) 0.70 mm (b) 0.50 mm
(c) 0.75 mm (d) 0.80 mm

20. The following observations were taken for determining surface tensiton T of water by capillary method :
Diameter of capilary, $D = 1.25 \times 10^{-2}$ m
rise of water, $h = 1.45 \times 10^{-2}$ m
Using $g = 9.80$ m/s^2 and the simplified relation $T = \frac{rhg}{2} \times 10^3$ N/m, the possible error in surface tension is closest to : **[2017]**
(a) 2.4% (b) 10% (c) 0.15% (d) 1.5%

21. The density of a material in the shape of a cube is determined by measuring three sides of the cube and its mass. If the relative errors in measuring the mass and length are respectively 1.5% and 1%, the maximum error in determining the density is: **[2018]**
(a) 2.5% (b) 3.5% (c) 4.5% (d) 6%

22. In the density measurement of a cube, the mass and edge length are measured as (10.00 ± 0.10) kg and (0.10 ± 0.01) m, respectively. The error in the measurement of density is: **[2019]**
(a) 0.01 kg/m^3 (b) 0.10 kg/m^3
(c) 0.31 kg/m^3 (d) 0.07 kg/m^3

23. The dimensions of $\frac{B^2}{2\mu_0}$, where B is magnetic field and μ_0 is the magnetic permeability of vacuum, is: **[2020]**
(a) MLT^{-2} (b) ML^2T^{-1}
(c) ML^2T^{-2} (d) $ML^{-1}T^{-2}$

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Answer Key														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(a)	(c)	(b)	(a)	(d)	(c)	(a)	(d)	(d)	(a)	(a)	(a)	(c)	(b)	(a)
16	17	18	19	20	21	22	23							
(b)	(d)	(c)	(d)	(d)	(c)	(c)	(d)							

Solutions

1. **(a)** Work $W = \vec{F}\cdot\vec{s} = Fs\cos\theta$

$\because\ \vec{A}\cdot\vec{B} = AB\cos\theta$

$= [MLT^{-2}][L] = [ML^2T^{-2}]$;

Torque, $\vec{\tau} = \vec{r}\times\vec{F} \Rightarrow \tau = rF\sin\theta$

$\because\ \vec{A}\times\vec{B} = AB\sin\theta$

$= [L]\,[MLT^{-2}] = [ML^2T^{-2}]$

2. **(c)** As we know, the velocity of light in free space is given by

$$C = \frac{1}{\sqrt{\mu_o\varepsilon_o}} = 3\times10^8[\text{m/s}]$$

$$\frac{1}{\mu_o\varepsilon_o} = C^2[\text{m/s}]^2$$

$= [LT^{-1}]^2$

$= [M^0L^2T^{-2}]$

3. **(b)** Momentum, $P = mv = [MLT^{-1}]$

Planck's constant,

$$h = \frac{E}{v}$$

$$= \frac{[ML^2T^{-2}]}{[T^{-1}]}$$

$= [ML^2T^{-1}]$

4. **(a)** According to, Stokes law,

$$F = 6\pi\eta rv \Rightarrow \eta = \frac{F}{6\pi r v}$$

$$\eta = \frac{[MLT^{-2}]}{[L][LT^{-1}]} \Rightarrow \eta = [ML^{-1}T^{-1}]$$

5. **(d)** Moment of Inertia, $I = MR^2$

$[I] = [ML^2]$

Moment of force, $\vec{\tau} = \vec{r}\times\vec{F}$

$\vec{\tau} = [L][MLT^{-2}] = [ML^2T^{-2}]$

6. **(c)** Magnitude of Lorentz formula $F = qvB\sin\theta$

$$B = \frac{F}{qv} = \frac{MLT^{-2}}{C\times LT^{-1}} = [MT^{-1}C^{-1}]$$

7. **(a)** Momentum, $p = m\times v$

Given, mass of a body = 3.513 kg speed of body

$= (3.513)\times(5.00) = 17.565$ kg m/s

$= 17.6$ (Rounding off)

8. **(d)** Least count of screw gauge = 0.01 mm

$\because \frac{0.5}{50}$ mm

Reading = [M.S.R. + C.S.R. × L.C.] – (zero error)

$= [3 + 35\times0.01] - (-0.03) = 3.38$ mm

9. **(d)** 30 Divisions of V.S. coincide with 29 divisions of M.S.

$\therefore$ 1 V.S.D $= \frac{29}{30}$ MSD

L.C. = 1 MSD – 1VSD

$= 1\text{ MSD} - \frac{29}{30}\text{ MSD}$

$= \frac{1}{30}$ MSD

$= \frac{1}{30}\times0.5° = 1$ minute.

10. **(a)** Number of significant figures in 23.023 = 5

Number of significant figures in 0.0003 = 1

Number of significant figures in $2.1\times10^{-3} = 2$

So, the radiation belongs to X-rays part of the spectrum.

11. **(a)** Least count, L.C. $= \frac{1}{100}$ mm

Diameter of wire = $MSR + CSR\times L.C.$

$\because$ 1 mm = 0.1 cm

$= 0 + \frac{1}{100}\times52 = 0.52$ mm $= 0.052$ cm

12. **(a)** According to ohm's law, V = IR

$R = \frac{V}{I}$

$\therefore$ Percentage error $= \frac{\text{Absolute error}}{\text{Measurement}} \times 10^2$

where, $\frac{\Delta V}{V} \times 100 = \frac{\Delta I}{I} \times 100 = 3\%$

then, $\frac{\Delta R}{R} \times 100 = \frac{\Delta V}{V} \times 10^2 + \frac{\Delta I}{I} \times 10^2$

$= 3\% + 3\% = 6\%$

13. **(c)** $\because$ Reading of Vernier = M.S.R. + V.S.R. × L.C.

M.S.R. = 58.5

V.S.R. = 09 division

L.C. of Vernier = 0.5°/30

Thus, $R = 58.5° + 9 \times \frac{0.5°}{30}$

R = 58.65°

14. **(b)** As we know, $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{R^2}$

$\Rightarrow \varepsilon_0 = \frac{q_1 q_2}{4\pi F R^2}$

Hence, $\varepsilon_0 = \frac{C^2}{N.m^2} = \frac{[AT]^2}{[MLT^{-2}][L^2]}$

$= [M^{-1} L^{-3} T^4 A^2]$

15. **(a)** The current voltage relation of diode is

$I = (e^{1000\,V/T} - 1)$ mA (given)

When, $I = 5mA$, $e^{1000\,V/T} = 6mA$

Also, $dI = (e^{1000\,V/T}) \times \frac{1000}{T}$

Error = ± 0.01 (By exponential function)

$= (6\,mA) \times \frac{1000}{300} \times (0.01) = 0.2$ mA

16. **(b)** Measured length of rod = 3.50 cm

For Vernier Scale with 1 Main Scale Division = 1 mm

9 Main Scale Division = 10 Vernier Scale Division,

Least count = 1 MSD – 1 VSD = 0.1 mm

17. **(d)** As, $g = 4\pi^2 \frac{L}{T^2}$

So, $\frac{\Delta g}{g} \times 100 = \frac{\Delta L}{L} \times 100 + 2\frac{\Delta T}{T} \times 100$

$= \frac{0.1}{20} \times 100 + 2 \times \frac{1}{90} \times 100 = 2.72 \simeq 3\%$

18. **(c)** $\Delta T = \frac{|\Delta T_1| + |\Delta T_2| + |\Delta T_3| + |\Delta T_4|}{4}$

$= \frac{2+1+3+0}{4} = 1.5$

As the resolution of measuring clock is 1.5 therefore the mean time should be 92 ± 1.5

19. **(d)** L.C. $= \frac{0.5}{50} = 0.01$ mm

Zero error = 5 × 0.01 = 0.05 mm (Negative)

Reading = (0.5 + 25 × 0.01) + 0.05 = 0.80 mm

20. **(d)** Surface tension, $T = \frac{rhg}{2} \times 10^3$

Relative error in surface tension,

$\frac{\Delta T}{T} = \frac{\Delta r}{r} + \frac{\Delta h}{h} + 0$

Percentage error

$100 \times \frac{\Delta T}{T} = \left(\frac{10^{-2} \times 0.01}{1.25 \times 10^{-2}} + \frac{10^{-2} \times 0.01}{1.45 \times 10^{-2}}\right) 100$

= (0.8 + 0.689)

= (1.489) = 1.489% ≅ 1.5%

21. **(c)** Density (d) $= \frac{\text{Mass (M)}}{\text{Volume (V)}} = \frac{M}{L^3}$

$\therefore$ Error in density, $\frac{\Delta d}{d} = \frac{\Delta M}{M} + \frac{3\Delta L}{L}$

$= 1.5\% + 3(1\%) = 4.5\%$

22. **(c)** $d = \frac{M}{V} = \frac{M}{L^3} = ML^{-3}$

$\frac{\Delta d}{d} = \frac{\Delta M}{M} + 3\frac{\Delta L}{L}$

$= \frac{0.10}{10.00} + 3\left(\frac{0.01}{0.10}\right) = 0.31 kgm^{-3}$

23. **(d)** The quantity $\frac{B^2}{2\mu_0}$ is the energy density of magnetic field.

$\Rightarrow \left[\frac{B^2}{2\mu_0}\right] = \frac{\text{Energy}}{Volume} = \frac{\text{Force} \times \text{displacement}}{(\text{displacement})^3}$

$= \left[\frac{ML^2T^{-2}}{L^3}\right] = ML^{-1}T^{-2}$

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Motion in a Straight Line

2

1. If a body looses half of its velocity on penetrating 3 cm in a wooden block, then how much will it penetrate more before coming to rest? **[2002]**
(a) 1 cm (b) 2 cm (c) 3 cm (d) 4 cm.

2. Speeds of two identical cars are u and $4u$ at the specific instant. The ratio of the respective distances in which the two cars are stopped from that instant is **[2002]**
(a) 1 : 1 (b) 1 : 4 (c) 1 : 8 (d) 1 : 16

3. From a building two balls A and B are thrown such that A is thrown upwards and B downwards (both vertically). If v_A and v_B are their respective velocities on reaching the ground, then **[2002]**
(a) $v_B > v_A$ (b) $v_A = v_B$
(c) $v_A > v_B$
(d) their velocities depend on their masses.

4. A car, moving with a speed of 50 km/hr, can be stopped by brakes after at least 6 m. If the same car is moving at a speed of 100 km/hr, the minimum stopping distance is **[2003]**
(a) 12 m (b) 18 m (c) 24 m (d) 6 m

5. A ball is released from the top of a tower of height h meters. It takes T seconds to reach the ground. What is the position of the ball at $\frac{T}{3}$ second **[2004]**
(a) $\frac{8h}{9}$ meters from the ground
(b) $\frac{7h}{9}$ meters from the ground
(c) $\frac{h}{9}$ meters from the ground
(d) $\frac{17h}{18}$ meters from the ground

6. An automobile travelling with a speed of 60 km/h, can brake to stop within a distance of 20m. If the car is going twice as fast i.e., 120 km/h, the stopping distance will be **[2004]**
(a) 60 m (b) 40 m (c) 20 m (d) 80 m

7. A car, starting from rest, accelerates at the rate f through a distance S, then continues at constant speed for time t and then decelerates at the rate $\frac{f}{2}$ to come to rest. If the total distance traversed is 15 S, then **[2005]**
(a) $S = \frac{1}{6}ft^2$ (b) $S = ft$
(c) $S = \frac{1}{4}ft^2$ (d) $S = \frac{1}{72}ft^2$

8. A particle is moving eastwards with a velocity of 5 ms^{-1}. In 10 seconds the velocity changes to 5 ms^{-1} northwards. The average acceleration in this time is **[2005]**
(a) $\frac{1}{2} ms^{-2}$ towards north
(b) $\frac{1}{\sqrt{2}} ms^{-2}$ towards north-east
(c) $\frac{1}{\sqrt{2}} ms^{-2}$ towards north-west
(d) zero

9. The relation between time t and distance x is $t = ax^2 + bx$ where a and b are constants. The acceleration is **[2005]**
(a) $-2bv^3$ (b) $-2abv^2$
(c) $2av^2$ (d) $-2av^3$

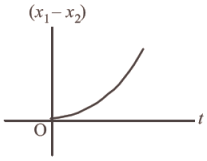
10. A particle located at $x = 0$ at time $t = 0$, starts moving along with the positive x-direction with a velocity 'v' that varies as $v = \alpha\sqrt{x}$. The displacement of the particle varies with time as **[2006]**

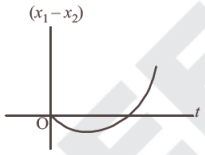
(a) t^2 (b) t (c) $t^{1/2}$ (d) t^3

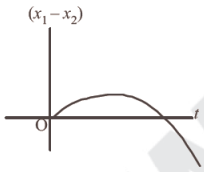
11. The velocity of a particle is $v = v_0 + gt + ft^2$. If its position is $x = 0$ at $t = 0$, then its displacement after unit time ($t = 1$) is **[2007]**

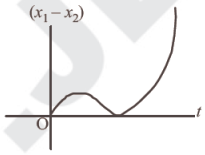
(a) $v_0 + g/2 + f$ (b) $v_0 + 2g + 3f$
(c) $v_0 + g/2 + f/3$ (d) $v_0 + g + f$

12. A body is at rest at $x = 0$. At $t = 0$, it starts moving in the positive x-direction with a constant acceleration. At the same instant another body passes through $x = 0$ moving in the positive x-direction with a constant speed. The position of the first body is given by $x_1(t)$ after time 't'; and that of the second body by $x_2(t)$ after the same time interval. Which of the following graphs correctly describes $(x_1 - x_2)$ as a function of time 't'? **[2008]**

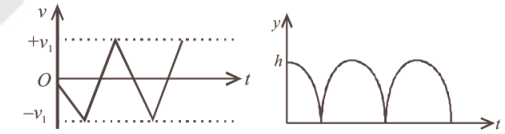
(a) 

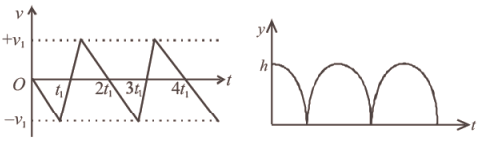
(b) 

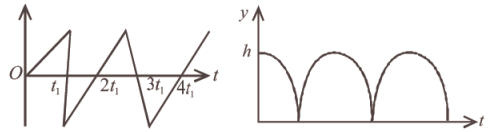
(c) 

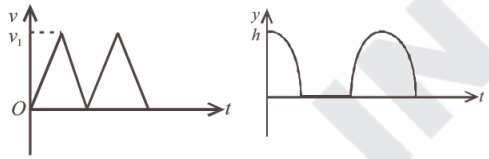
(d) 

13. Consider a rubber ball freely falling from a height $h = 4.9$ m onto a horizontal elastic plate. Assume that the duration of collision is negligible and the collision with the plate is totally elastic.
Then the velocity as a function of time and the height as a function of time will be : **[2009]**

(a) 

(b) 

(c) 

(d) 

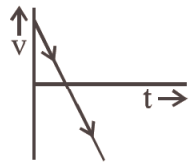
14. An object, moving with a speed of 6.25 m/s, is decelerated at a rate given by $\frac{dv}{dt} = -2.5\sqrt{v}$ where v is the instantaneous speed. The time taken by the object, to come to rest, would be: **[2011]**

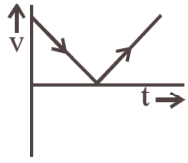
(a) 2 s (b) 4 s (c) 8 s (d) 1 s

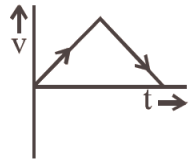
15. From a tower of height H, a particle is thrown vertically upwards with a speed u. The time taken by the particle, to hit the ground, is n times that taken by it to reach the highest point of its path. The relation between H, u and n is: **[2014]**

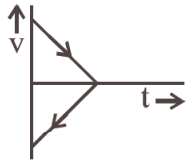
(a) $2gH = n^2u^2$ (b) $gH = (n-2)^2 u^2 d$
(c) $2gH = nu^2 (n-2)$ (d) $gH = (n-2)u^2$

16. A body is thrown vertically upwards. Which one of the following graphs correctly represent the velocity vs time? **[2017]**

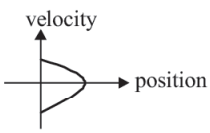
(a) 

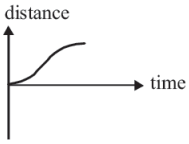
(b) 

(c) 

(d) 

17. All the graphs below are intended to represent the same motion. One of them does it incorrectly. Pick it up. **[2018]**

(a) 

(b) 

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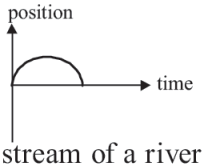
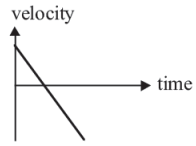
(c) 

(d) 

18. The stream of a river is flowing with a speed of 2 km/h. A swimmer can swim at a speed of 4 km/h. What should be the direction of the swimmer with respect to the flow of the river to cross the river straight? **[2019]**

(a) 90° (b) 150° (c) 120° (d) 60°

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(a)	(d)	(b)	(c)	(a)	(d)	(d)	(c)	(d)	(a)	(c)	(b)	(b)	(a)	(c)
16	17	18												
(a)	(b)	(c)												

Solutions

1. **(a)** In first case

$u_1 = u$; $v_1 = \frac{u}{2}$, $s_1 = 3$ cm, $a_1 = ?$

Using, $v_1^2 - u_1^2 = 2a_1s_1$ ...(i)

$\left(\frac{u}{2}\right)^2 - u^2 = 2 \times a \times 3$

$\Rightarrow \quad a = \frac{-u^2}{8}$

In second case: Assuming the same retardation

$u_2 = u/2$; $v_2 = 0$; $s_2 = ?$; $a_2 = \frac{-u^2}{8}$

$v_2^2 - u_2^2 = 2a_2 \times s_2$ ...(ii)

$\therefore \; 0 - \frac{u^2}{4} = 2\left(\frac{-u^2}{8}\right) \times s_2$

$\Rightarrow s_2 = 1$ cm

2. **(d)** **For first car**

$u_1 = u, v_1 = 0, a_1 = -a, s_1 = s_1$

As $v_1^2 - u_1^2 = 2a_1s_1$

$\Rightarrow -u^2 = -2as_1$

$\Rightarrow u^2 = 2as_1$

$\Rightarrow s_1 = \frac{u^2}{2a}$ ...(i)

For second car

$u_2 = 4u, v_1 = 0, a_2 = -a, s_2 = s_2$

$\therefore \quad v_2^2 - u_2^2 = 2a_2s_2$

$\Rightarrow -(4u)^2 = 2(-a)s_2$

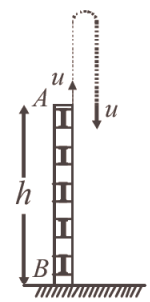
$\Rightarrow 16u^2 = 2as_2$

$\Rightarrow s_2 = \frac{8u^2}{a}$ ...(ii)

Dividing (i) and (ii),

$\frac{s_1}{s_2} = \frac{u^2}{2a} \cdot \frac{a}{8u^2} = \frac{1}{16}$

3. **(b)** Ball A is thrown upwards with velocity u from the building. During its downward journey when it comes back to the point of throw, its speed is equal to the speed of throw (u). So, for the journey of both the balls from point A to B.



We can apply $v^2 - u^2 = 2gh$.

As u, g, h are same for both the balls, $v_A = v_B$

4. **(c)** **Fir first case :** Initial velocity,

$u = 50 \times \frac{5}{18}$ m/s,

$v = 0, s = 6\text{m}, a = a$

Using, $v^2 - u^2 = 2as$

$\Rightarrow 0^2 - \left(50 \times \frac{5}{18}\right)^2 = 2 \times a \times 6$

$\Rightarrow -\left(50 \times \frac{5}{18}\right)^2 = 2 \times a \times 6$

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$a = -\dfrac{250 \times 250}{324 \times 2 \times 6} \approx = -16 \text{ ms}^{-2}$.

Case-2 : Initial velocity, u = 100 km/hr

$= 100 \times \dfrac{5}{18}$ m/sec

$v = 0, s = s, a = a$

As $v^2 - u^2 = 2as$

$\Rightarrow 0^2 - \left(100 \times \dfrac{5}{18}\right)^2 = 2as$

$\Rightarrow -\left(100 \times \dfrac{5}{18}\right)^2 = 2 \times (-16) \times 5$

$s = \dfrac{500 \times 500}{324 \times 32} = 24\text{m}$

5. (a) We have $s = ut + \dfrac{1}{2}gt^2$,

$\Rightarrow \quad h = 0 \times T + \dfrac{1}{2}gT^2$

$\Rightarrow \quad h = \dfrac{1}{2}gT^2$

Vertical distance moved in time $\dfrac{T}{3}$ is

$h' = \dfrac{1}{2}g\left(\dfrac{T}{3}\right)^2 \Rightarrow h' = \dfrac{1}{2} \times \dfrac{gT^2}{9} = \dfrac{h}{9}$

$\therefore$ Position of ball from ground $= h - \dfrac{h}{9}$

$= \dfrac{8h}{9}$

6. (d) In first case speed,

$u = 60 \times \dfrac{5}{18}\text{m/s} = \dfrac{50}{3}\text{m/s}$

$d = 20\text{m}$,

Let retardation be a then

$(0)^2 - u^2 = -2ad$

or $\quad u^2 = 2ad \qquad \ldots(\text{i})$

In second case speed, $u' = 120 \times \dfrac{5}{18}$

$= \dfrac{100}{3}\text{m/s}$

and $(0)^2 - u'^2 = -2ad'$

or $\quad u'^2 = 2ad' \qquad \ldots(\text{ii})$

(ii) divided by (i) gives,

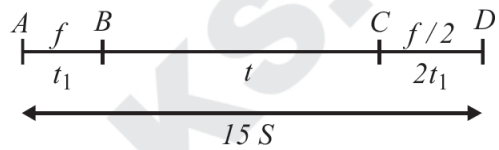
$4 = \dfrac{d'}{d} \Rightarrow d' = 4 \times 20 = 80\text{m}$

7. (d) Let car starts from A from rest and moves up to point B with acceleration f.

Distance, $AB = S = \dfrac{1}{2}ft_1^2$

Distance, $BC = (ft_1)t$

Distance, $CD = \dfrac{u^2}{2a} = \dfrac{(ft_1)^2}{2(f/2)} = ft_1^2 = 2S$



Total distance, $AD = AB + BC + CD = 15S$

$AD = S + BC + 2S$

$\Rightarrow \quad S + f\,t_1 t + 2S = 15\,S$

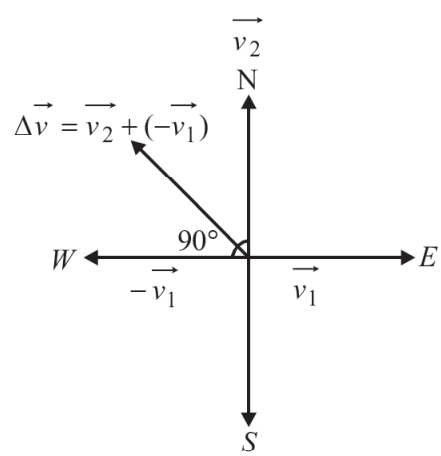
$\Rightarrow \quad f\,t_1 t = 12\,S \qquad \ldots\ldots\ldots\ldots (\text{i})$

$\dfrac{1}{2}f\,t_1^2 = S \qquad \ldots\ldots\ldots\ldots (\text{ii})$

Dividing (i) by (ii), we get $t_1 = \dfrac{t}{6}$

$\Rightarrow \quad S = \dfrac{1}{2}f\left(\dfrac{t}{6}\right)^2 = \dfrac{f\,t^2}{72}$

8. (c)



Initial velocity, $\vec{v_1} = 5\hat{i}$,

Final velocity, $\vec{v_2} = 5\hat{j}$,

Change in velocity $\Delta\vec{v} = (\vec{v}_2 - \vec{v}_1)$

$= \sqrt{v_1^2 + v_2^2 + 2v_1v_2\cos 90}$

$= \sqrt{5^2 + 5^2 + 0} = 5\sqrt{2}\text{m/s}$

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[As $|v_1| = |v_2| = 5$ m/s]

Avg. acceleration $= \dfrac{\Delta \vec{v}}{t}$

$= \dfrac{5\sqrt{2}}{10} = \dfrac{1}{\sqrt{2}}\,\text{m/s}^2$

$\tan\theta = \dfrac{5}{-5} = -1$

which means θ is in the second quadrant. (towards north-west)

9. (d) Given, $t = ax^2 + bx$;

Diff. with respect to time (t)

$\dfrac{d}{dt}(t) = a\dfrac{d}{dt}(x^2) + b\dfrac{dx}{dt} = a.2x\dfrac{dx}{dt} + \text{b.v.}$

$\Rightarrow 1 = 2axv + bv = v(2ax + b)$ (v = velocity)

$2ax + b = \dfrac{1}{v}$.

Again differentiating, we get

$2a\dfrac{dx}{dt} + 0 = -\dfrac{1}{v^2}\dfrac{dv}{dt}$

$\Rightarrow a = \dfrac{dv}{dt} = -2av^3 \left(\because \dfrac{dx}{dt} = v\right)$

10. (a) $v = \alpha\sqrt{x}$,

$\Rightarrow \dfrac{dx}{dt} = \alpha\sqrt{x}$

$\Rightarrow \dfrac{dx}{\sqrt{x}} = \alpha\, dt$

Integrating both sides,

$\int_0^x \dfrac{dx}{\sqrt{x}} = \alpha\int_0^t dt$; $\left[\dfrac{2\sqrt{x}}{1}\right]_0^x = \alpha[t]_0^t$

$\Rightarrow 2\sqrt{x} = \alpha t \Rightarrow x = \dfrac{\alpha^2}{4}t^2$

11. (c) We know that, $v = \dfrac{dx}{dt}$

$\Rightarrow dx = v\, dt$

Integrating, $\int_0^x dx = \int_0^t v\, dt$

or $x = \int_0^t (v_0 + gt + ft^2)\, dt$

$= \left[v_0 t + \dfrac{gt^2}{2} + \dfrac{ft^3}{3}\right]_0^t$

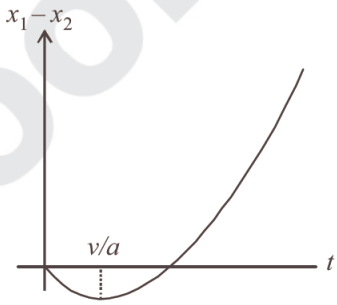
or, $x = v_0 t + \dfrac{gt^2}{2} + \dfrac{ft^3}{3}$

At $t = 1$, $x = v_0 + \dfrac{g}{2} + \dfrac{f}{3}$.

12. (b) For the body starting from rest, distance travelled (x_1) is given by

$x_1 = 0 + \dfrac{1}{2}at^2$

$\Rightarrow x_1 = \dfrac{1}{2}at^2$



For the body moving with constant speed

$x_2 = vt$

$\therefore x_1 - x_2 = \dfrac{1}{2}at^2 - vt$

at $t = 0, x_1 - x_2 = 0$

This equation is of parabola.

For $t < \dfrac{v}{a}$; the slope is negative

For $t = \dfrac{v}{a}$; the slope is zero

For $t > \dfrac{v}{a}$; the slope is positive

These characteristics are represented by graph (b).

13. (b) For downward motion $v = -gt$

The velocity of the rubber ball increases in downward direction and we get a straight line between v and t with a negative slope.

Also applying $y - y_0 = ut + \dfrac{1}{2}at^2$

We get $y - h = -\dfrac{1}{2}gt^2 \Rightarrow y = h - \dfrac{1}{2}gt^2$

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The graph between y and t is a parabola with $y = h$ at $t = 0$. As time increases y decreases.

For upward motion.

The ball suffer elastic collision with the horizontal elastic plate therefore the direction of velocity is reversed and the magnitude remains the same.

Here $v = u - gt$ where u is the velocity just after collision.

As t increases, v decreases. We get a straight line between v and t with negative slope.

Also $y = ut - \frac{1}{2}gt^2$

All these characteristics are represented by graph (b).

14. (a) Given, $\frac{dv}{dt} = -2.5\sqrt{v}$

$\Rightarrow \frac{dv}{\sqrt{v}} = -2.5\ dt$

Integrating,

$\int_{6.25}^{0} v^{-1/2} dv = -2.5\int_0^t dt$

$\Rightarrow \left[\frac{v^{+1/2}}{(1/2)}\right]_{6.25}^{0} = -2.5[t]_0^t$

$\Rightarrow -2(6.25)^{1/2} = -2.5t$

$\Rightarrow -2 \times 2.5$

$= -2.5t$

$\Rightarrow t = 25$

15. (c) Speed on reaching ground

$v = \sqrt{u^2 + 2gh}$

Now, $v = u + at$

$\Rightarrow \sqrt{u^2 + 2gh} = -u + gt$

Time taken to reach highest point is

$t = \frac{u}{g}$,

$\Rightarrow t = \frac{u + \sqrt{u^2 + 2gH}}{g} = \frac{nu}{g}$

(from question)

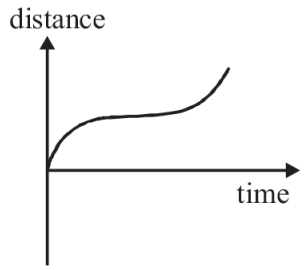
$\Rightarrow 2gH = n(n-2)u^2$

16. (a) For a body thrown vertically upwards acceleration remains constant ($a = -g$) and velocity at anytime t is given by $V = u - gt$

During rise velocity decreases linearly and during fall velocity increases linearly and direction is opposite to each other.

Hence graph (a) correctly depicts velocity versus time.

17. (b) Graphs in option (c) position-time and option (a) velocity-position are corresponding to velocity-time graph option (d) and its distance-time graph is as given below. Hence distance-time graph option (b) is incorrect.

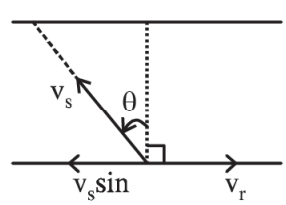


18. (c) To cross the river straight

$V_s \sin\theta = V_r \quad \therefore \sin\theta = \frac{v_r}{v_s} = \frac{2}{4} = \frac{1}{2}$

$\therefore \theta = 30°$

Direction of swimmer with respect to flow $= 90° + 30° = 120°$



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3 Motion in a Plane

1. A boy playing on the roof of a 10 m high building throws a ball with a speed of 10m/s at an angle of 30º with the horizontal. How far from the throwing point will the ball be at the height of 10 m from the ground? **[2003]**

$[g = 10\text{m/s}^2, \sin 30^o = \frac{1}{2}, \cos 30^o = \frac{\sqrt{3}}{2}]$

(a) 5.20m (b) 4.33m
(c) 2.60m (d) 8.66m

2. The co-ordinates of a moving particle at any time 't' are given by $x = \alpha t^3$ and $y = \beta t^3$. The speed of the particle at time 't' is given by **[2003]**

(a) $3t\sqrt{\alpha^2+\beta^2}$ (b) $3t^2\sqrt{\alpha^2+\beta^2}$

(c) $t^2\sqrt{\alpha^2+\beta^2}$ (d) $\sqrt{\alpha^2+\beta^2}$

3. A projectile can have the same range 'R' for two angles of projection. If 'T_1' and 'T_2' to be time of flights in the two cases, then the product of the two time of flights is directly proportional to. **[2004]**

(a) R (b) $\frac{1}{R}$ (c) $\frac{1}{R^2}$ (d) R^2

4. Which of the following statements is **FALSE** for a particle moving in a circle with a constant angular speed ? **[2004]**
   (a) The acceleration vector points to the centre of the circle
   (b) The acceleration vector is tangent to the circle
   (c) The velocity vector is tangent to the circle
   (d) The velocity and acceleration vectors are perpendicular to each other.

5. A ball is thrown from a point with a speed 'v_0' at an elevation angle of θ. From the same point and at the same instant, a person starts running with a constant speed $\frac{'v_0'}{2}$ to catch the ball. Will the person be able to catch the ball? If yes, what should be the angle of projection θ? **[2004]**

(a) No (b) Yes, 30°
(c) Yes, 60° (d) Yes, 45°

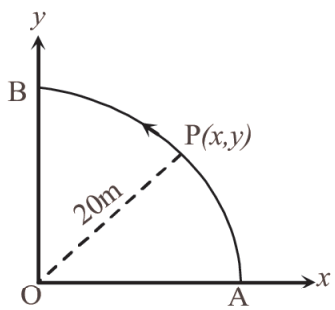
6. A particle has an initial velocity of $3\hat{i}+4\hat{j}$ and an acceleration of $0.4\hat{i}+0.3\hat{j}$. Its speed after 10 s is : **[2009]**

(a) $7\sqrt{2}$ units (b) 7 units
(c) 8.5 units (d) 10 units

7. A particle is moving with velocity $\vec{v} = k(y\hat{i}+x\hat{j})$, where k is a constant. The general equation for its path is **[2010]**

(a) $y = x^2$ + constant
(b) $y^2 = x$ + constant
(c) xy = constant
(d) $y^2 = x^2$ + constant

8. A point P moves in counter-clockwise direction on a circular path as shown in the figure. The movement of 'P' is such that it sweeps out a length $s = t^3 + 5$, where s is in metres and t is in seconds. The radius of the path is 20 m. The acceleration of 'P' when $t = 2$ s is nearly. **[2010]**



(a) $13 m/s^2$ (b) $12 m/s^2$
(c) $7.2 ms^2$ (d) $14 m/s^2$

9. For a particle in uniform circular motion, the acceleration $\vec{a}$ at a point P(R,θ) on the circle of radius R is (Here θ is measured from the x-axis) **[2010]**

(a) $-\frac{v^2}{R}\cos\theta\ \hat{i}+\frac{v^2}{R}\sin\theta\ \hat{j}$

(b) $-\frac{v^2}{R}\sin\theta\ \hat{i}+\frac{v^2}{R}\cos\theta\ \hat{j}$

(c) $-\frac{v^2}{R}\cos\theta\ \hat{i}-\frac{v^2}{R}\sin\theta\ \hat{j}$

(d) $\frac{v^2}{R}\hat{i}+\frac{v^2}{R}\hat{j}$

10. A water fountain on the ground sprinkles water all around it. If the speed of water coming out of the fountain is v, the total area around the fountain that gets wet is : **[2011]**

(a) $\pi\frac{v^4}{g^2}$ (b) $\frac{\pi}{2}\frac{v^4}{g^2}$

(c) $\pi\frac{v^2}{g^2}$ (d) $\pi\frac{v^2}{g}$

11. A boy can throw a stone up to a maximum height of 10 m. The maximum horizontal distance that the boy can throw the same stone up to will be **[2012]**

(a) $20\sqrt{2}$ m (b) 10m

(c) $10\sqrt{2}$ m (d) 20m

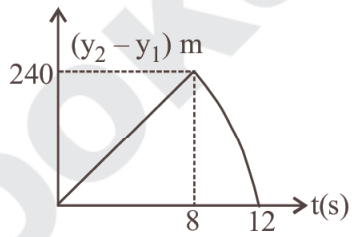
12. A projectile is given an initial velocity of $(\hat{i}+2\hat{j})$ m/s, where $\hat{i}$ is along the ground and $\hat{j}$ is along the vertical. If g = 10 m/s^2, the equation of its trajectory is : **[2013]**

(a) $y = x - 5x^2$ (b) $y = 2x - 5x^2$
(c) $4y = 2x - 5x^2$ (d) $4y = 2x - 25x^2$

13. Two stones are thrown up simultaneously from the edge of a cliff 240 m high with initial speed of 10 m/s and 40 m/s respectively. Which of the following graph best represents the time variation of relative position of the second stone with respect to the first? **[2015]**

(Assume stones do not rebound after hitting the ground and neglect air resistance, take $g = 10 m/s^2$)

(*The figures are schematic and not drawn to scale*)

(a)


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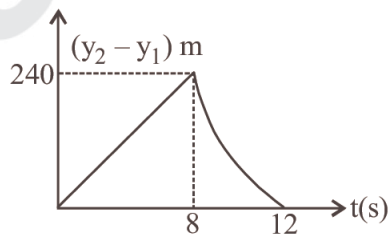
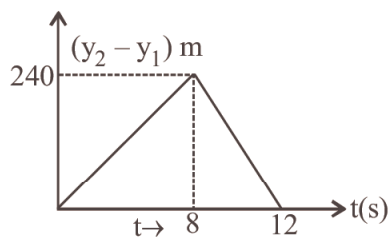
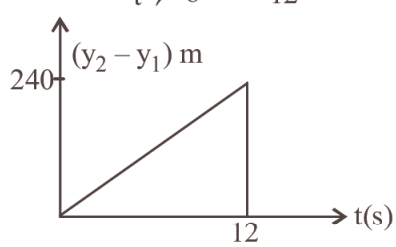


(c)


(d)


14. A particle is moving with a velocity $\vec{v} = K(y\hat{i} + x\hat{j})$, where K is a constant. The general equation for its path is:

(a) $y = x^2$ + constant (b) $y^2 = x$ + constant
(c) $y^2 = x^2$ + constant (d) xy = constant

[2019]

Answer Key												
1	2	3	4	5	6	7	8	9	10	11	12	13
(d)	(b)	(a)	(b)	(c)	(a)	(a)	(d)	(c)	(a)	(d)	(b)	(b)
14												
(c)												

Solutions

1. **(d)** Horizontal range is required

$$R = \frac{u^2 \sin 2\theta}{g} = \frac{(10)^2 \sin(2\times 30°)}{10} = 5\sqrt{3}$$

= 8.66 m

2. **(b)** Coordinates of moving particle at time 't' are

$x = \alpha t^3$ and $y = \beta t^3$

$$v_x = \frac{dx}{dt} = 3\alpha t^2 \text{ and } v_y = \frac{dy}{dt} = 3\beta t^2$$

$$\therefore\ v = \sqrt{v_x^2 + v_y^2} = \sqrt{9\alpha^2 t^4 + 9\beta^2 t^4}$$

$$= 3t^2\sqrt{\alpha^2 + \beta^2}$$

3. **(a)** A projectile have same range for two angle Let one angle be θ, then other is 90° – θ

$$T_1 = \frac{2u\sin\theta}{g}, T_2 = \frac{2u\cos\theta}{g}$$

then, $T_1T_2 = \dfrac{4u^2 \sin\theta\cos\theta}{g} = 2R$

$$(\because\ R = \frac{u^2\sin^2\theta}{g})$$

Thus, it is proportional to R. (Range)

4. **(b)** Only option (b) is false since acceleration vector is always radial for uniform circular motion.

5. **(c)** Yes, Man will catch the ball, if the horizontal component of velocity becomes equal to the constant speed of man.

$$\frac{v_o}{2} = v_o\cos\theta$$

or $\theta = 60°$

6. **(a)** Given $\vec{u} = 3\hat{i} + 4\hat{j}$, $\vec{a} = 0.4\hat{i} + 0.3\hat{j}$, t=10s

From 1st equatoin of motion.

$$a = \frac{v-u}{t}$$

$\therefore\ v = at\ tu$

$$\Rightarrow v = (0.4\hat{i} + 0.3\hat{j})\times 10 + (3\hat{i} + 4\hat{j})$$

$$\Rightarrow\ 4\hat{i} + 3\hat{j} + 3\hat{j} + 4\hat{j}$$

$$\Rightarrow\ v = 7\hat{i} + 7\hat{j}$$

$$\Rightarrow\ |\vec{v}| = \sqrt{7^2 + 7^2} = 7\sqrt{2} \text{ unit.}$$

7. **(a)** $v = k(yi + xj)$

$v = kyi + kxj$

$$\frac{dx}{dt} = ky,\ \frac{dy}{dt} = kx$$

$$\frac{dy}{dx} = \frac{dy}{dt}\times\frac{dt}{dx}$$

$$\frac{dy}{dx} = \frac{kx}{ky}$$

$ydy = xdx$ ...(i)

Integrating equation (i)

$$\int ydy = \int x\cdot dx$$

$y^2 = x^2 + c$

8. **(d)** $s = t^3 + 5$, $r = 20$m, $t = 5$ sec

velocity, $v = \dfrac{ds}{dt} = 3t^2$

Linear acceleration $a_t = \dfrac{dv}{dt} = 6t$

Centripetal acceleration $a_c = \dfrac{v^2}{R} = \dfrac{9t^4}{R}$

At $t = 2s$, $at = 6 \times 2 = 12$ m/s^2

$$a_c = \frac{9\times 16}{20} = 7.2 \text{ m/s}^2$$

Resultant acceleration

$$= \sqrt{a_t^2 + a_c^2}$$

$$= \sqrt{(12)^2 + (7.2)^2} = \sqrt{144 + 51.84}$$

$$= \sqrt{195.84} = 14 \text{ m/s}^2$$

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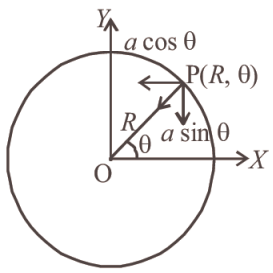
9. **(c)** Acceleration,

$a = \frac{v^2}{R}$ towards the centre

$\vec{a} = -a_c \cos\theta(\hat{i}) - a_c \sin\theta(\hat{j})$

$= -\frac{v^2}{R}\cos\theta\,\hat{i} - \frac{v^2}{R}\sin\theta\,\hat{j}$



10. **(a)** Let, total area around fountain

$A = \pi R_{max}^2$ ...(i)

Where $R_{max} = \frac{v^2 \sin 2\theta}{g} = \frac{v^2 \sin 90°}{g} = \frac{v^2}{g}$ ...(ii)

From equation (i) and (ii)

$A = \pi \frac{v^4}{g^2}$

11. **(d)** $R = \frac{u^2 \sin^2\theta}{g}$, $H = \frac{u^2 \sin^2\theta}{2g}$

H_{max} at $2\theta = 90°$

$H_{max} = \frac{u^2}{2g}$

$\frac{u^2}{2g} = 10 \Rightarrow u^2 = 10g \times 2$

$R = \frac{u^2 \sin 2\theta}{g} \Rightarrow R_{max} = \frac{u^2}{g}$

$R_{max} = \frac{10 \times g \times 2}{g} = 20$ metre

12. **(b)** From equation, $\vec{v} = \hat{i} + 2\hat{j}$

$\Rightarrow x = t$ ...(i)

$y = 2t - \frac{1}{2}(10t^2)$ ...(ii)

From (i) and (ii), $y = 2x - 5x^2$

13. **(b)** $y_1 = 10t - 5t^2; y_2 = 40t - 5t^2$

for $y_1 = -240$m, $t = 8s$

$\therefore$ $y_2 - y_1 = 30t$ for $t \le 8s$.

for $t > 8s$,

$y_2 - y_1 = 240 - 40t - \frac{1}{2}gt^2$

14. **(c)** From given equation,

$\vec{v} = k\left(y\hat{i} + x\hat{j}\right) = ky\hat{i} + kx\hat{j} = V_x\hat{i} + V_y\hat{j}$

$\frac{dx}{dt} = ky$ and $\frac{dy}{dt} = kx$

Now, $\frac{\frac{dy}{dt}}{\frac{dx}{dt}} = \frac{x}{y} = \frac{dy}{dx} \Rightarrow ydy = xdx$

Integrating both sides we get $y^2 = x^2 + c$

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4 Laws of Motion

1. A lift is moving down with acceleration a. A man in the lift drops a ball inside the lift. The acceleration of the ball as observed by the man in the lift and a man standing stationary on the ground are respectively **[2002]**
   (a) g, g (b) $g - a, g - a$
   (c) $g - a, g$ (d) a, g

2. When forces F_1, F_2, F_3 are acting on a particle of mass m such that F_2 and F_3 are mutually perpendicular, then the particle remains stationary. If the force F_1 is now removed then the acceleration of the particle is **[2002]**
   (a) F_1/m (b) F_2F_3/mF_1
   (c) $(F_2 - F_3)/m$ (d) F_2/m.

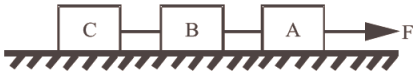
3. The minimum velocity (in ms^{-1}) with which a car driver must traverse a flat curve of radius 150 m and coefficient of friction 0.6 to avoid skidding is **[2002]**
   (a) 60 (b) 30 (c) 15 (d) 25

4. A solid sphere, a hollow sphere and a ring are released from top of an inclined plane (frictionless) so that they slide down the plane. Then maximum acceleration down the plane is for (no rolling) **[2002]**
   (a) solid sphere (b) hollow sphere
   (c) ring (d) all same.

5. Two forces are such that the sum of their magnitudes is 18 N and their resultant is 12 N which is perpendicular to the smaller force. Then the magnitudes of the forces are **[2002]**
   (a) 12 N, 6 N (b) 13 N, 5 N
   (c) 10 N, 8 N (d) 16N, 2N.

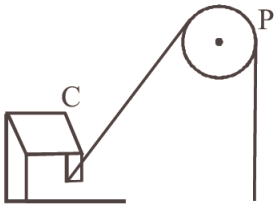
6. A light string passing over a smooth light pulley connects two blocks of masses m_1 and m_2 (vertically). If the acceleration of the system is $g/8$, then the ratio of the masses is **[2002]**
   (a) 8 : 1 (b) 9 : 7 (c) 4 : 3 (d) 5 : 3.

7. Three identical blocks of masses $m = 2$ kg are drawn by a force $F = 10.2$ N with an acceleration of 0.6 ms^{-2} on a frictionless surface, then what is the tension (in N) in the string between the blocks B and C? **[2002]**



   (a) 9.2 (b) 3.4 (c) 4 (d) 9.8

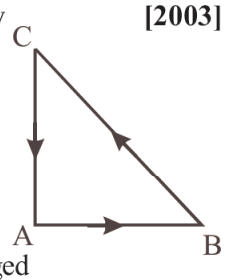
8. One end of a massless rope, which passes over a massless and frictionless pulley P is tied to a hook C while the other end is free. Maximum tension that the rope can bear is 360 N. With what value of maximum safe acceleration (in ms^{-2}) can a man of 60 kg climb on the rope? **[2002]**



   (a) 16 (b) 6 (c) 4 (d) 8

9. A spring balance is attached to the ceiling of a lift. A man hangs his bag on the spring and the spring reads 49 N, when the lift is stationary. If the lift moves downward with an acceleration of $5 m/s^2$, the reading of the spring balance will be **[2003]**
   (a) 24 N (b) 74 N (c) 15 N (d) 49 N

10. Three forces start acting simultaneously on a particle moving with velocity, $\vec{v}$. These forces are represented in magnitude and direction by the three sides of a triangle ABC. The particle will now move with velocity **[2003]**



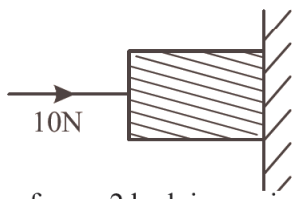
(a) less than $\vec{v}$

(b) greater than $\vec{v}$

(c) $|\vec{v}|$ in the direction of the largest force BC

(d) $\vec{v}$, remaining unchanged

11. A horizontal force of 10 N is necessary to just hold a block stationary against a wall. The coefficient of friction between the block and the wall is 0.2. The weight of the block is **[2003]**



(a) 20 N

(b) 50 N

(c) 100 N

(d) 2 N

12. A marble block of mass 2 kg lying on ice when given a velocity of 6 m/s is stopped by friction in 10 s. Then the coefficient of friction is **[2003]**

(a) 0.02 (b) 0.03 (c) 0.04 (d) 0.06

13. A block of mass M is pulled along a horizontal frictionless surface by a rope of mass m. If a force P is applied at the free end of the rope, the force exerted by the rope on the block is **[2003]**

(a) $\frac{Pm}{M+m}$ (b) $\frac{Pm}{M-m}$

(c) P (d) $\frac{PM}{M+m}$

14. A light spring balance hangs from the hook of the other light spring balance and a block of mass M kg hangs from the former one. Then the true statement about the scale reading is **[2003]**

(a) both the scales read M kg each

(b) the scale of the lower one reads M kg and of the upper one zero

(c) the reading of the two scales can be anything but the sum of the reading will be M kg

(d) both the scales read $M/2$ kg each

15. A rocket with a lift-off mass 3.5×10^4 kg is blasted upwards with an initial acceleration of $10 m/s^2$. Then the initial thrust of the blast is

(a) 3.5×10^5 N (b) 7.0×10^5 N **[2003]**

(c) 14.0×10^5 N (d) 1.75×10^5 N

16. Two masses $m_1 = 5g$ and $m_2 = 4.8$ kg tied to a string are hanging over a light frictionless pulley. What is the acceleration of the masses when left free to move? ($g = 9.8 m/s^2$) **[2004]**

(a) $5 m/s^2$

(b) $9.8 m/s^2$

(c) $0.2 m/s^2$

(d) $4.8 m/s^2$

17. A block rests on a rough inclined plane making an angle of 30° with the horizontal. The coefficient of static friction between the block and the plane is 0.8. If the frictional force on the block is 10 N, the mass of the block (in kg) is (take $g = 10 m/s^2$) **[2004]**

(a) 1.6 (b) 4.0 (c) 2.0 (d) 2.5

18. A smooth block is released at rest on a 45° incline and then slides a distance 'd'. The time taken to slide is 'n' times as much to slide on rough incline than on a smooth incline. The coefficient of friction is **[2005]**

(a) $\mu_k = \sqrt{1-\frac{1}{n^2}}$ (b) $\mu_k = 1-\frac{1}{n^2}$

(c) $\mu_s = \sqrt{1-\frac{1}{n^2}}$ (d) $\mu_s = 1-\frac{1}{n^2}$

19. A parachutist after bailing out falls 50 m without friction. When parachute opens, it decelerates at $2 m/s^2$. He reaches the ground with a speed of 3 m/s. At what height, did he bail out? **[2005]**

(a) 182 m (b) 91 m (c) 111 m (d) 293 m

20. An annular ring with inner and outer radii R_1 and R_2 is rolling without slipping with a uniform angular speed. The ratio of the forces experienced by the two particles situated on the inner and outer parts of the ring, $\frac{F_1}{F_2}$ is **[2005]**

(a) $\left(\frac{R_1}{R_2}\right)^2$ (b) $\frac{R_2}{R_1}$

(c) $\frac{R_1}{R_2}$ (d) 1

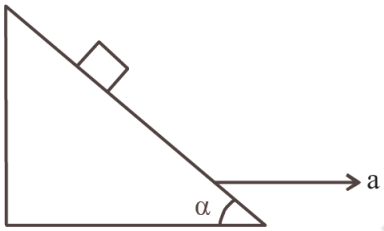
21. The upper half of an inclined plane with inclination ϕ is perfectly smooth while the lower half is rough. A body starting from rest at the top will again come to rest at the bottom if the coefficient of friction for the lower half is given by **[2005]**

(a) $2\cos\phi$ (b) $2\sin\phi$
(c) $\tan\phi$ (d) $2\tan\phi$

22. A particle of mass 0.3 kg subject to a force $F = -kx$ with $k = 15$ N/m . What will be its initial acceleration if it is released from a point 20 cm away from the origin ? **[2005]**

(a) 15 m/s^2 (b) 3 m/s^2
(c) 10 m/s^2 (d) 5 m/s^2

23. A block is kept on a frictionless inclined surface with angle of inclination 'α'. The incline is given an acceleration 'a' to keep the block stationary. Then a is equal to **[2005]**



(a) $g \operatorname{cosec} \alpha$ (b) $g / \tan \alpha$
(c) $g \tan \alpha$ (d) g

24. Consider a car moving on a straight road with a speed of 100 m/s . The distance at which car can be stopped is [$\mu_k = 0.5$] **[2005]**

(a) 1000 m (b) 800 m
(c) 400 m (d) 100 m

25. A ball of mass 0.2 kg is thrown vertically upwards by applying a force by hand. If the hand moves 0.2 m while applying the force and the ball goes upto 2 m height further, find the magnitude of the force. (Consider $g = 10$ m/s^2). **[2006]**

(a) 4 N (b) 16 N
(c) 20 N (d) 22 N

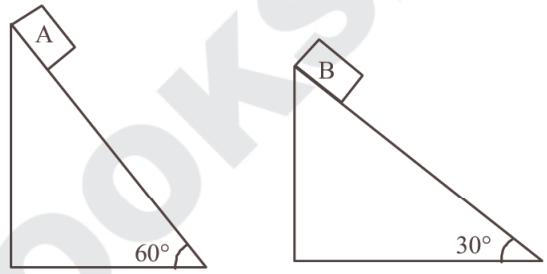
26. A player caught a cricket ball of mass 150 g moving at a rate of 20 m/s. If the catching process is completed in 0.1 s, the force of the blow exerted by the ball on the hand of the player is equal to **[2006]**

(a) 150 N (b) 3 N
(c) 30 N (d) 300 N

27. A block of mass m is connected to another block of mass M by a spring (massless) of spring constant k. The block are kept on a smooth horizontal plane. Initially the blocks are at rest and the spring is unstretched. Then a constant force F starts acting on the block of mass M to pull it. Find the force on the block of mass m. **[2007]**

(a) $\dfrac{MF}{(m+M)}$ (b) $\dfrac{mF}{M}$
(c) $\dfrac{(M+m)F}{m}$ (d) $\dfrac{mF}{(m+M)}$

28. Two fixed frictionless inclined planes making an angle 30° and 60° with the vertical are shown in the figure. Two blocks A and B are placed on the two planes. What is the relative vertical acceleration of A with respect to B? **[2010]**



(a) 4.9 ms^{-2} in horizontal direction
(b) 9.8 ms^{-2} in vertical direction
(c) Zero
(d) 4.9 ms^{-2} in vertical direction

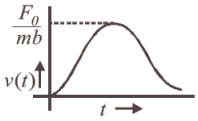
29. The minimum force required to start pushing a body up rough (frictional coefficient μ) inclined plane is F_1 while the minimum force needed to prevent it from sliding down is F_2. If the inclined plane makes an angle θ from the horizontal such that $\tan\theta = 2\mu$ then the ratio $\dfrac{F_1}{F_2}$ is **[2011 RS]**

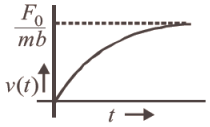
(a) 1 (b) 2 (c) 3 (d) 4

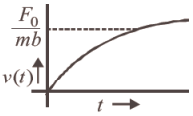
30. If a spring of stiffness 'k' is cut into parts 'A' and 'B' of length $\ell_A : \ell_B = 2 : 3$, then the stiffness of spring 'A' is given by **[2011 RS]**

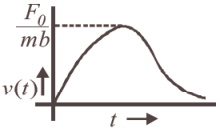
(a) $\dfrac{3k}{5}$ (b) $\dfrac{2k}{5}$ (c) k (d) $\dfrac{5k}{2}$

31. A particle of mass m is at rest at the origin at time $t = 0$. It is subjected to a force $F(t) = F_0 e^{-bt}$ in the x direction. Its speed $v(t)$ is depicted by which of the following curves? **[2012]**

(a)


(b)


(c)


(d)


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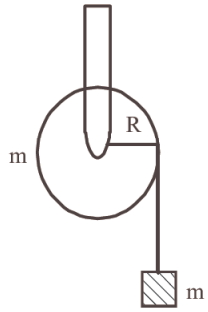
32. A mass 'm' is supported by a massless string wound around a uniform hollow cylinder of mass m and radius R. If the string does not slip on the cylinder, with what acceleration will the mass fall or release? **[2014]**



(a) $\frac{2g}{3}$

(b) $\frac{g}{2}$

(c) $\frac{5g}{6}$

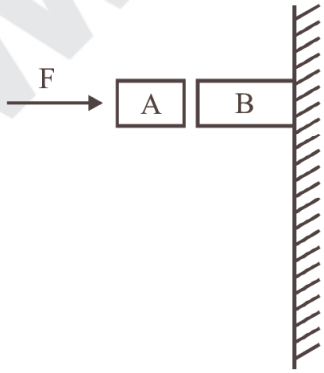
(d) g

33. A block of mass m is placed on a surface with a vertical cross section given by $y = \frac{x^3}{6}$. If the coefficient of friction is 0.5, the maximum height above the ground at which the block can be placed without slipping is: **[2014]**

(a) $\frac{1}{6}$m (b) $\frac{2}{3}$m

(c) $\frac{1}{3}$m (d) $\frac{1}{2}$m

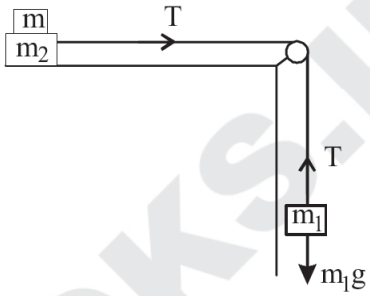
34. Given in the figure are two blocks A and B of weight 20 N and 100 N, respectively. These are being pressed against a wall by a force F as shown. If the coefficient of friction between the blocks is 0.1 and between block B and the wall is 0.15, the frictional force applied by the wall on block B is: **[2015]**



(a) 120 N (b) 150 N

(c) 100 N (d) 80 N

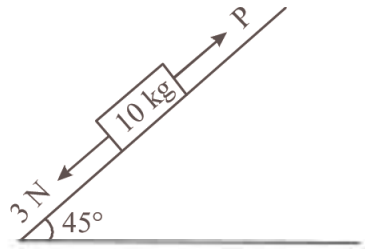
35. Two masses $m_1 = 5$ kg and $m_2 = 10$ kg, connected by an inextensible string over a frictionless pulley, are moving as shown in the figure. The coefficient of friction of horizontal surface is 0.15. The minimum weight m that should be put on top of m_2 to stop the motion is: **[2018]**



(a) 18.3 kg (b) 27.3 kg

(c) 43.3 kg (d) 10.3 kg

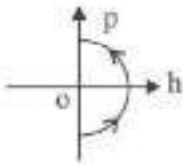
36. A block of mass 10 kg is kept on a rough inclined plane as shown in the figure. A force of 3 N is applied on the block. The coefficient of static friction between the plane and the block is 0.6. What should be the minimum value of force P, such that the block doesnot move downward? (take $g = 10$ ms^{-2}) **[2019]**

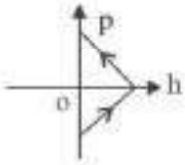


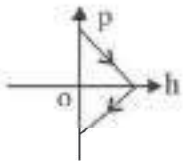
(a) 32 N (b) 18 N

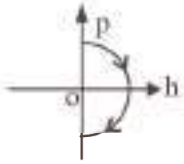
(c) 23 N (d) 25 N

37. A ball is thrown vertically up (taken as +z-axis) from the ground. The correct momentum-height (p-h) diagram is: **[2019]**

(a)


(b)


(c)


(d)


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Answer Key														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(c)	(a)	(b)	(d)	(b)	(b)	(b)	(c)	(a)	(d)	(d)	(d)	(d)	(a)	(b)
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
(c)	(c)	(b)	(d)	(c)	(d)	(c)	(c)	(a)	(d)	(c)	(d)	(d)	(c)	(d)
31	32	33	34	35	36	37								
(c)	(b)	(a)	(a)	(b)	(a)	(d)								

Solutions

1. **(c)** **Case - I:** For the man standing in the lift, the acceleration of the ball

$\vec{a}_{bm} = \vec{a}_b - \vec{a}_m \Rightarrow a_{bm} = g - a$

Case - II: The man standing on the ground, the acceleration of the ball

$\vec{a}_{bm} = \vec{a}_b - \vec{a}_m \Rightarrow a_{bm} = g - 0 = g$

2. **(a)** When forces F_1, F_2 and F_3 are acting on the particle, it remains in equilibrium. Force F_2 and F_3 are perpendicular to each other,

$F_1 = F_2 + F_3$

$\therefore \quad F_1 = \sqrt{F_2^2 + F_3^2}$

The force F_1 is now removed, so, resultant of F_2 and F_3 will now make the particle move with force equal to F_1.

Then, acceleration, $a = \dfrac{F_1}{m}$

3. **(b)** The maximum velocity of the car is

$v_{max} = \sqrt{\mu r g}$

Here $\mu = 0.6$, $r = 150$ m, $g = 9.8$

$v_{max} = \sqrt{0.6 \times 150 \times 9.8} \simeq 30 \text{m/s}$

4. **(d)** This is a case of sliding (if plane is friction less) and therefore the acceleration of all the bodies is same.

5. **(b)** Let the two forces be F_1 and F_2 and let $F_2 < F_1$. R is the resultant force.

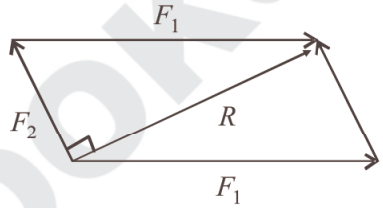
Given $F_1 + F_2 = 18$ ...(i)

From the figure $F_2^2 + R^2 = F_1^2$

$F_1^2 - F_2^2 = R^2$

$\therefore \quad F_1^2 - F_2^2 = 144$ ...(ii)

Only option (b) follows equation (i) and (ii).

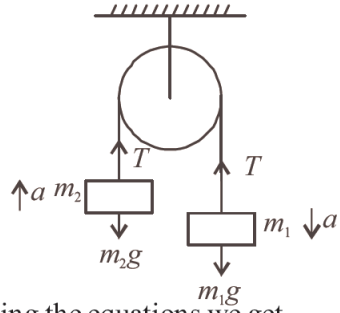


6. **(b)** **For mass m_1**

$m_1 g - T = m_1 a$ ...(i)

For mass m_2

$T - m_2 g = m_2 a$ ...(ii)



Adding the equations we get

$a = \dfrac{(m_1 - m_2)g}{m_1 + m_2}$

Here $a = \dfrac{g}{8}$

$\therefore \quad \dfrac{1}{8} = \dfrac{\dfrac{m_1}{m_2} - 1}{\dfrac{m_1}{m_2} + 1} \quad \Rightarrow \dfrac{m_1}{m_2} + 1 = 8\dfrac{m_1}{m_2} - 8$

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

7. **(b)** Force = mass × acceleration

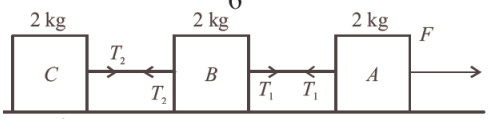
$\therefore \quad F = (m + m + m) \times a$

$F = 3\text{m} \times \text{a}$

$$a = \frac{F}{3m}$$

$$\therefore\ a = \frac{10.2}{6}\,\text{m/s}^2$$

$$\therefore\ T_2 = ma = 2 \times \frac{10.2}{6} = 3.4\text{N}$$



8. **(c)** Tension, $T = 360$ N

Mass of a man m = 60 kg

$mg - T = ma$

$$\therefore\quad a = g - \frac{T}{m}$$

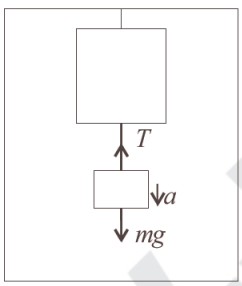
$$= 10 - \frac{360}{60} = 4m/s^2$$

9. **(a)** When lift is stationary, $W_1 = mg$ ...(i)

When the lift descends with acceleration, a

$$W_2 = m(g - a)$$

$$W_2 = \frac{49}{10}(10 - 5) = 24.5\ N$$

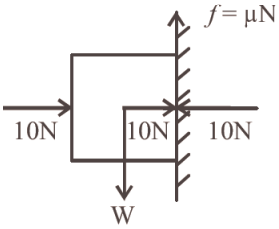


10. **(d)** Resultant force is zero, as three forces are represented by the sides of a triangle taken in the same order. From Newton's second law, $\vec{F}_{net} = m\vec{a}$.

Therefore, acceleration is also zero *i.e.*, velocity remains unchanged.

11. **(d)** Horizontal force, $N = 10$ N.

Coefficient of friction $\mu = 0.2$.



The block will be stationary so long as Force of friction = weight of block

$\therefore\quad \mu N = W$

$\Rightarrow 0.2 \times 10 = W$

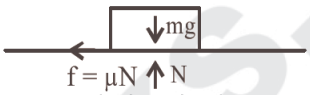
$\Rightarrow W = 2N$

12. **(d)** $u = 6$ m/s, $v = 0$, $t = 10s$, $a = ?$

Acceleration $a = \frac{v-u}{t}$

$$\Rightarrow\quad a = \frac{0-6}{10}$$

$$\Rightarrow\quad a = \frac{-6}{10} = -0.6\text{m/s}^2$$



The retardation is due to the frictional force

$\therefore\quad f = ma$

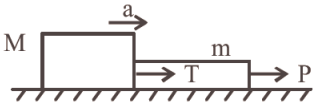
$\Rightarrow \mu N = ma$

$\Rightarrow \mu mg = ma$

$$\Rightarrow\quad \mu = \frac{ma}{mg}$$

$$\Rightarrow \mu = \frac{a}{g} = \frac{0.6}{10} = 0.06$$

13. **(d)** Taking the rope and the block as a system



we get $P = (m + M)a$

$\therefore$ Acceleration produced, $a = \frac{P}{m+M}$

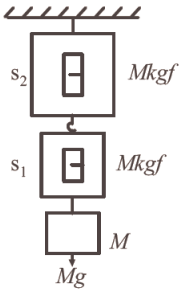
Taking the block as a system,

Force on the block, $F = Ma$

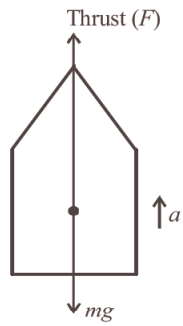
$$\therefore\ F = \frac{MP}{m+M}$$

14. **(a)** The Earth exerts a pulling force Mg. The block in turn exerts a reaction force Mg on the spring of spring balance S_1 which therefore shows a reading of M kgf.

As both the springs are massless. Therefore, it exerts a force of Mg on the spring of spring balance S_2 which shows the reading of M *kgf*.



15. (b) In the absence of air resistance, if the rocket moves up with an acceleration a, then thrust $F = mg + ma$



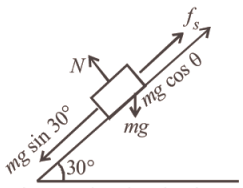
$\therefore \quad F = m(g + a) = 3.5 \times 10^4 (10+10)$
$= 7 \times 10^5$ N

16. (c) Here, $m_1 = 5$kg and $m_2 = 4.8$ kg.
If a is the acceleration of the masses,
$m_1 a = m_1 g - T$ ...(i)
$m_2 a = T - m_2 g$ ...(ii)
Solving (i) and (ii) we get

$$a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) g$$

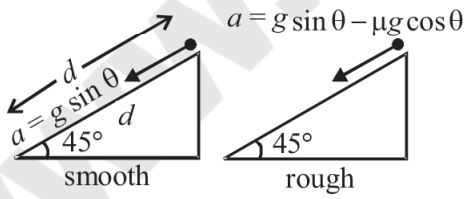
$$\Rightarrow \quad a = \frac{(5-4.8)\times 9.8}{(5+4.8)} \text{ m/s}^2 = 0.2 \text{ m/s}^2$$

17. (c)



Since the body is at rest on the inclined plane,
$mg \sin 30°$ = Force of friction
$\Rightarrow m \times 10 \times \sin 30° = 10$
$\Rightarrow m \times 5 = 10 \Rightarrow m = 2.0$ kg

18. (b)



On smooth inclined plane, acceleration of the body = $g \sin \theta$. Let d be the distance travelled

$$\therefore \quad d = \frac{1}{2}(g\sin\theta)t_1^2,$$

$$t_1 = \sqrt{\frac{2d}{g\sin\theta}},$$

On rough inclined plane,

$$a = \frac{mg\sin\theta - \mu R}{m}$$

$$\Rightarrow \quad a = \frac{mg\sin\theta - \mu mg\cos\theta}{m}$$

$$\Rightarrow \quad a = g\sin\theta - \mu_k g\cos\theta$$

$$\therefore \quad d = \frac{1}{2}(g\sin\theta - \mu\hat{k}g\cos\theta)t_2^2$$

$$t_2 = \sqrt{\frac{2d}{g\sin\theta - \mu\hat{k}g\cos\theta}}$$

According to question, $t_2 = nt_1$

$$n\sqrt{\frac{2d}{g\sin\theta}} = \sqrt{\frac{2d}{g\sin\theta - \mu\hat{k}g\cos\theta}}$$

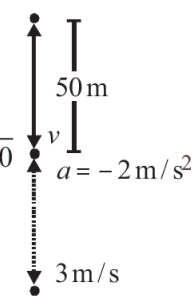
Here, μ is coefficient of kinetic friction as the block moves over the inclined plane.

$$\therefore \quad \sin\theta = (\sin\theta - \mu\hat{k}\cos\theta)n^2$$

$$\Rightarrow \quad n = \frac{1}{\sqrt{1-\mu_k}} \quad \Rightarrow \quad n^2 = \frac{1}{1-\mu_k}$$

$$\Rightarrow \quad \mu_k = 1 - \frac{1}{n^2}$$

19. (d) Initially, the parachutist falls under gravity.



$u = \sqrt{2gh}$

$u = \sqrt{2 \times 9.8 \times 50} = \sqrt{980}$

He reachs the ground with a speed of 3 m/s.

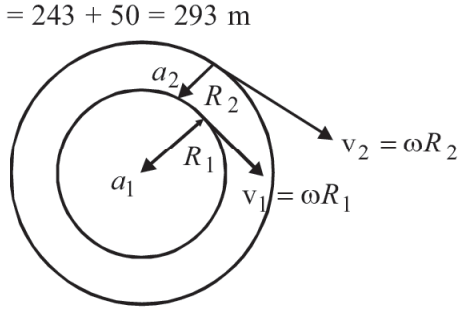
$\therefore \quad v = 3$m/s

Using $v^2 - u^2 = 2aS$

$$\Rightarrow \quad S = \frac{v^2 - u^2}{2 \times 2} = \frac{3^2 - 980}{4} \approx 243 \text{ m}$$

Initially he has fallen 50 m.
$\therefore$ Total height from where he bailed out = 243 + 50 = 293 m

20. (c)



Let m is the mass of each particle and ω is the angular speed of the annular ring.

$$a_1 = \frac{v_1^2}{R_1} = \frac{\omega^2 R_1^2}{R_1} = \omega^2 R_1$$

$$a_2 = \frac{v_2^2}{R_2} = \omega^2 R_2$$

Taking particle masses equal

$$\frac{F_1}{F_2} = \frac{ma_1}{ma_2} = \frac{mR_1\omega^2}{mR_2\omega^2} = \frac{R_1}{R_2}$$

ALTERNATE SOLUTION

The force experienced by any particle is only along radial direction.

Force experienced by the particle, $F = m\omega^2 R$

$$\therefore \frac{F_1}{F_2} = \frac{R_1}{R_2}$$

21. (d) For first half

acceleration $= g \sin \phi$;

For second half

acceleration $= -(g \sin\phi - \mu g \cos\phi)$

For the block to come to rest at the bottom, acceleration in I half = retardation in II half.

$$g \sin\phi = -(g \sin\phi - \mu g \cos\phi)$$

$$\Rightarrow \mu = 2 \tan\phi$$

ALTERNATE SOLUTION

According to work-energy theorem, $W = \Delta K = 0$

(Since initial and final speeds are zero)

$\therefore$ Workdone by friction + Work done by gravity = 0

i.e., $-(\mu\, mg \cos\phi)\frac{\ell}{2} + mg\ell \sin\phi = 0$

or $\frac{\mu}{2}\cos\phi = \sin\phi$ or $\mu = 2\tan\phi$

22. (c) Mass $(m) = 0.3$ kg

Force, $F = m.a = -kx$

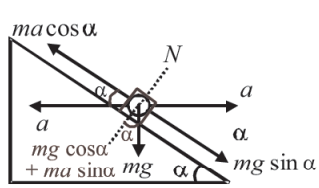
$\Rightarrow$ $ma = -15x$

$\Rightarrow$ $0.3a = -15x$

$$\Rightarrow a = -\frac{15}{0.3}x = \frac{-150}{3}x = -50x$$

$a = -50 \times 0.2 = 10 \text{m/s}^2$

23. (c) When the incline is given an acceleration a towards the right, the block receives a reaction *ma* towards left.



For block to remain stationary, Net force along the incline should be zero.

$mg \sin\alpha = ma \cos\alpha \Rightarrow a = g \tan\alpha$

24. (a) Given, initial velocity, $u = 100$m/s.

Final velocity, $v = 0$.

Acceleration, $a = \mu_k g = 0.5 \times 10$

$v^2 - u^2 = 2as$ or

$\Rightarrow$ $0^2 - u^2 = 2(-\mu_k g)s$

$$\Rightarrow -100^2 = 2 \times -\frac{1}{2} \times 10 \times s$$

$\Rightarrow$ $s = 1000$ m

25. (d) For the motion of ball, just after the throwing

$v = 0$, $s = 2$m, $a = -g = -10\text{ms}^{-2}$

$v^2 - u^2 = 2as$ for upward journey

$\Rightarrow -u^2 = 2(-10) \times 2 \Rightarrow u^2 = 40$

When the ball is in the hands of the thrower

$u = 0$, $v = \sqrt{40}$ ms^{-1}

$s = 0.2$m

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

$\Rightarrow 40 - 0 = 2\ (a)\ 0.2 \Rightarrow a = 100$ m/s^2

$\therefore F = ma = 0.2 \times 100 = 20\ N$

$\Rightarrow N - mg = 20 \Rightarrow N = 20 + 2 = 22N$

ALTERNATE SOLUTION

$W_{hand} + W_{gravity} = \Delta K$

$\Rightarrow F(0.2) + (0.2)(10)(2.2) = 0 \Rightarrow F = 22\ N$

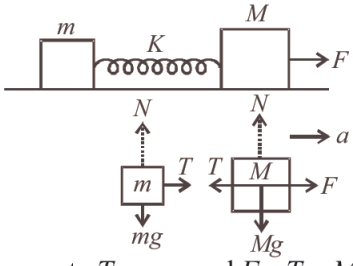
26. (c) Given, mass of cricket ball, $m = 150\,g = 0.15$ kg

Initial velocity, $u = 20$ m/s

Force,

$$F = \frac{m(v-u)}{t} = \frac{0.15(0-20)}{0.1} = 30\,N$$

27. (d) Writing free body-diagrams for *m* & *M*,



we get $T = ma$ and $F - T = Ma$

where T is force due to spring

$\Rightarrow$ $F - ma = Ma$ or, $F = Ma + ma$

$\therefore$ Acceleration of the system

$$a = \frac{F}{M+m}.$$

Now, force acting on the block of mass m is

$$ma = m\left(\frac{F}{M+m}\right) = \frac{mF}{m+M}.$$

If a is the acceleration along the inclined plane, then

28. (d) $mg \sin\theta = ma$

$\therefore a = g \sin\theta$

$\therefore$ Vertical component of acceleration $= g \sin^2\theta$

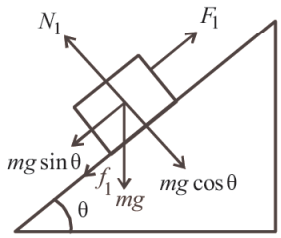
$\therefore$ Relative vertical acceleration of A with respect to B is

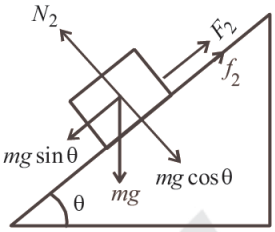
$g(\sin^2 60 - \sin^2 30]$

$= g\left(\frac{3}{4} - \frac{1}{4}\right) = \frac{g}{2} = 4.9 \text{ m/s}^2$

in vertical direction

29. (c)





When the body slides up the inclined plane, then

$$mg \sin\theta + f_1 = F_1$$

or, $F_1 = mg \sin\theta + \mu mg \cos\theta$

When the body slides down the inclined plane, then

$$mg \sin\theta - f_2 = F_2$$

or $F_2 = mg \sin\theta - \mu mg \cos\theta$

$$\therefore \frac{F_1}{F_2} = \frac{\sin\theta + \mu\cos\theta}{\sin\theta - \mu\cos\theta}$$

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

30. (d) It is given $\ell_A : \ell_B = 2 : 3$

$$\ell_A = \frac{2\ell}{5}, \quad \ell_B = \left(\frac{3\ell}{5}\right)$$

$\therefore$ We know that $k \propto \frac{1}{\ell}$

If initial spring constant is k, then

$$k\ell = k_A \ell_A = k_B \ell_B$$

$$k\ell = k_A\left(\frac{2\ell}{5}\right)$$

$$k_A = \frac{5k}{2}$$

31. (c) Given that $F(t) = F_0 e^{-bt}$

$$\Rightarrow m\frac{dv}{dt} = F_0 e^{-bt}$$

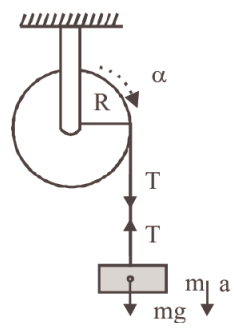
$$\frac{dv}{dt} = \frac{F_0}{m} e^{-bt}$$

$$\int_0^v dv = \frac{F_0}{m}\int_0^t e^{-bt} dt$$

$$v = \frac{F_0}{m}\left[\frac{e^{-bt}}{-b}\right]_0^t = \frac{F_0}{mb}\left[-\left(e^{-bt} - e^{-0}\right)\right]$$

$$\Rightarrow v = \frac{F_0}{mb}\left[1 - e^{-bt}\right]$$

32. (b) From figure,



Acceleration $a = R\alpha$ ...(i)

and $mg - T = ma$ ...(ii)

From equation (i) and (ii)

$$T \times R = mR^2\alpha = mR^2\left(\frac{a}{R}\right)$$

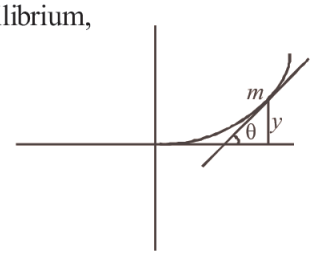
or $T = ma$

$\Rightarrow mg - ma = ma$

$\Rightarrow a = \frac{g}{2}$

33. (a) At limiting equilibrium,

$\mu = \tan\theta$



$\tan\theta = \mu = \frac{dy}{dx} = \frac{x^2}{2}$ (from question)

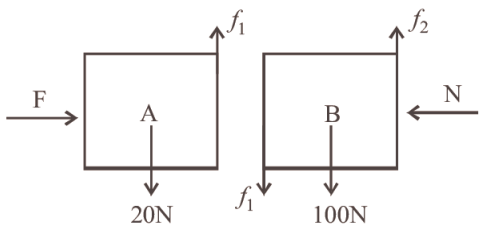
$\because$ Coefficient of friction $\mu = 0.5$

$\therefore \quad 0.5 = \frac{x^2}{2}$

$\Rightarrow \quad x = \pm 1$

Now, $y = \frac{x^3}{6} = \frac{1}{6} m$

34. (a)

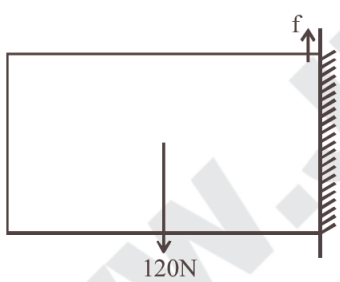


Assuming both the blocks are stationary

N = F

$f_1 = 20$ N

$f_2 = 100 + 20 = 120$N



Considering the two blocks as one system and due to equilibrium $f = 120$N

35. (b) Given : $m_1 = 5$kg; $m_2 = 10$kg; $\mu = 0.15$

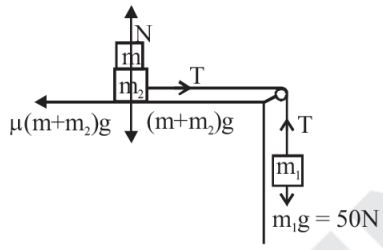
FBD for m_1, $m_1 g - T = m_1 a$

$\Rightarrow 50 - T = 5 \times a$

and, $T - 0.15\,(m + 10)g = (10 + m)a$

For rest $a = 0$

or, $50 = 0.15\,(m + 10)\,10$

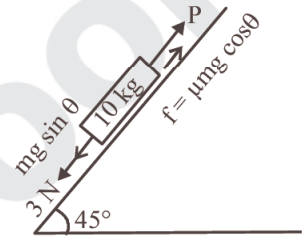


$\Rightarrow \quad 5 = \frac{3}{20}(m + 10)$

$\frac{100}{3} = m + 10 \quad \therefore \; m = 23.3$kg;

close to option (b)

36. (a)



For equilibrium

$3 + mg\sin\theta = P + \mu mg\cos\theta$

$\Rightarrow 3 + 10 \times 10 \times \frac{1}{\sqrt{2}}$

$= P + 0.6 \times 10 \times 10 \times \cos 45°$

$\therefore \quad P = 31.28 \approx 32$ N

37. (d) $v^2 = u^2 - 2gh$

or $v = \sqrt{u^2 - 2gh}$

Momentum, $p = mv$

$\therefore p = m\sqrt{u^2 - 2gh}$

Therefore graph between p and h cannot have straight line.

(b) and (c) are not possible.

During upward journey as h increases, p decreases and in downward journey as h decreases p increases. Therefore (d) is the correct option.

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5 Work, Energy and Power

1. Consider the following two statements :**[2003]**
   A. Linear momentum of a system of particles is zero
   B. Kinetic energy of a system of particles is zero. Then
   (a) A does not imply B and B does not imply A
   (b) A implies B but B does not imply A
   (c) A does not imply B but B implies A
   (d) A implies B and B implies A
2. A wire suspended vertically from one of its ends is stretched by attaching a weight of 200N to the lower end. The weight stretches the wire by 1 mm. Then the elastic energy stored in the wire is **[2003]**
   (a) 0.2 J (b) 10 J
   (c) 20 J (d) 0.1 J
3. A spring of spring constant 5×10^3 N/m is stretched initially by 5cm from the unstretched position. Then the work required to stretch it further by another 5 cm is **[2003]**
   (a) 12.50 N-m (b) 18.75 N-m
   (c) 25.00 N-m (d) 6.25 N-m
4. A body is moved along a straight line by a machine delivering a constant power. The distance moved by the body in time 't' is proportional to **[2003]**
   (a) $t^{3/4}$ (b) $t^{3/2}$
   (c) $t^{1/4}$ (d) $t^{1/2}$
5. A particle moves in a straight line with retardation proportional to its displacement. Its loss of kinetic energy for any displacement x is proportional to **[2004]**
   (a) x (b) e^x
   (c) x^2 (d) $\log_e x$
6. A uniform chain of length 2 m is kept on a table such that a length of 60 cm hangs freely from the edge of the table. The total mass of the chain is 4 kg. What is the work done in pulling the entire chain on the table ? **[2004]**
   (a) 12 J (b) 3.6 J
   (c) 7.2 J (d) 1200 J
7. A force $\vec{F} = (5\vec{i} + 3\vec{j} + 2\vec{k})N$ is applied over a particle which displaces it from its origin to the point $\vec{r} = (2\vec{i} - \vec{j})m$. The work done on the particle in joules is **[2004]**
   (a) +10 (b) +7
   (c) –7 (d) +13
8. A body of mass 'm', accelerates uniformly from rest to 'v_1' in time 't_1'. The instantaneous power delivered to the body as a function of time 't' is **[2004]**
   (a) $\frac{mv_1t^2}{t_1}$ (b) $\frac{mv_1^2t}{t_1^2}$
   (c) $\frac{mv_1t}{t_1}$ (d) $\frac{mv_1^2t}{t_1}$
9. A particle is acted upon by a force of constant magnitude which is always perpendicular to the velocity of the particle, the motion of the particles takes place in a plane. It follows that **[2004]**
   (a) its kinetic energy is constant
   (b) its acceleration is constant
   (c) its velocity is constant
   (d) it moves in a straight line
10. The block of mass M moving on the frictionless horizontal surface collides with the spring of spring constant k and compresses it by length L. The maximum momentum of the block after collision is **[2005]**

(a) $\frac{kL^2}{2M}$ (b) $\sqrt{Mk}\ L$

(c) $\frac{ML^2}{k}$ (d) zero

11. A spherical ball of mass 20 kg is stationary at the top of a hill of height 100 m. It rolls down a smooth surface to the ground, then climbs up another hill of height 30 m and finally rolls down to a horizontal base at a height of 20 m above the ground. The velocity attained by the ball is **[2005]**

(a) 20 m/s (b) 40 m/s

(c) $10\sqrt{30}$ m/s (d) 10 m/s

12. A body of mass m is accelerated uniformly from rest to a speed v in a time *T*. The instantaneous power delivered to the body as a function of time is given by **[2005]**

(a) $\frac{mv^2}{T^2}.t^2$ (b) $\frac{mv^2}{T^2}.t$

(c) $\frac{1}{2}\frac{mv^2}{T^2}.t^2$ (d) $\frac{1}{2}\frac{mv^2}{T^2}.t$

13. A mass 'm' moves with a velocity '*v*' and collides inelastically with another identical mass . After collision the 1st mass moves with velocity $\frac{v}{\sqrt{3}}$ in a direction perpendicular to the initial direction of motion. Find the speed of the 2nd mass after collision. **[2005]**

(a) $\sqrt{3}v$ (b) v

(c) $\frac{v}{\sqrt{3}}$ (d) $\frac{2}{\sqrt{3}}v$

14. A bomb of mass 16kg at rest explodes into two pieces of masses 4 kg and 12 kg. The velolcity of the 12 kg mass is $4\ ms^{-1}$. The kinetic energy of the other mass is **[2006]**

(a) 144 J (b) 288 J

(c) 192 J (d) 96 J

15. A particle of mass 100g is thrown vertically upwards with a speed of 5 m/s. The work done by the force of gravity during the time the particle goes up is **[2006]**

(a) –0.5 J (b) –1.25 J

(c) 1.25 J (d) 0.5 J

16. The potential energy of a 1 kg particle free to move along the x-axis is given by

$$V(x) = \left(\frac{x^4}{4} - \frac{x^2}{2}\right) J.$$

The total mechanical energy of the particle is 2 J. Then, the maximum speed (in m/s) is **[2006]**

(a) $\frac{3}{\sqrt{2}}$ (b) $\sqrt{2}$

(c) $\frac{1}{\sqrt{2}}$ (d) 2

17. A 2 kg block slides on a horizontal floor with a speed of 4m/s. It strikes a uncompressed spring, and compresses it till the block is motionless. The kinetic friction force is 15N and spring constant is 10,000 N/m. The spring compresses by **[2007]**

(a) 8.5 cm (b) 5.5 cm

(c) 2.5 cm (d) 11.0 cm

18. An athlete in the olympic games covers a distance of 100 m in 10 s. His kinetic energy can be estimated to be in the range **[2008]**

(a) 200 J - 500 J

(b) 2×10^5 J - 3×10^5 J

(c) 20,000 J - 50,000 J

(d) 2,000 J - 5,000 J

19. A block of mass 0.50 kg is moving with a speed of $2.00\ ms^{-1}$ on a smooth surface. It strikes another mass of 1.00 kg and then they move together as a single body. The energy loss during the collision is **[2008]**

(a) 0.16 J (b) 1.00 J

(c) 0.67 J (d) 0.34 J

20. The potential energy function for the force between two atoms in a diatomic molecule is approximately given by $U(x) = \frac{a}{x^{12}} - \frac{b}{x^6}$, where *a* and *b* are constants and *x* is the distance between the atoms. If the dissociation energy of the molecule is $D = [U(x = \infty] - U_{\text{at equilibrium}}]$, *D* is **[2010]**

(a) $\frac{b^2}{2a}$ (b) $\frac{b^2}{12a}$

(c) $\frac{b^2}{4a}$ (d) $\frac{b^2}{6a}$

21. **Statement -1:** Two particles moving in the same direction do not lose all their energy in a completely inelastic collision. **[2010]**

Statement -2 : Principle of conservation of momentum holds true for all kinds of collisions.

(a) Statement -1 is true, Statement -2 is true ; Statement -2 is the correct explanation of Statement -1.

(b) Statement -1 is true, Statement -2 is true; Statement -2 is **not** the correct explanation of Statement -1

(c) Statement -1 is false, Statement -2 is true.

(d) Statement -1 is true, Statement -2 is false.

22. At time $t = 0$ a particle starts moving along the x-axis. If its kinetic energy increases uniformly with time 't', the net force acting on it must be proportional to **[2011 RS]**

(a) constant (b) t

(c) $\frac{1}{\sqrt{t}}$ (d) $\sqrt{t}$

23. This question has statement I and statement II. Of the four choices given after the statements, choose the one that best describes the two statements.

Statement - I: Apoint particle of mass m moving with speed υ collides with stationary point particle of mass M. If the maximum energy loss possible is given as $f\left(\frac{1}{2}mv^2\right)$ then $f = \left(\frac{m}{M+m}\right)$.

Statement - II: Maximum energy loss occurs when the particles get stuck together as a result of the collision. **[2013]**

(a) Statement - I is true, Statment - II is true, Statement - II is the correct explanation of Statement - I.

(b) Statement-I is true, Statment - II is true, Statement - II is not the correct explanation of Statement - II.

(c) Statement - I is true, Statment - II is false.

(d) Statement - I is false, Statment - II is true.

24. When a rubber-band is stretched by a distance x, it exerts restoring force of magnitude $F = ax + bx^2$ where a and b are constants. The work done in stretching the unstretched rubber-band by L is: **[2014]**

(a) $aL^2 + bL^3$ (b) $\frac{1}{2}\left(aL^2 + bL^3\right)$

(c) $\frac{aL^2}{2} + \frac{bL^3}{3}$ (d) $\frac{1}{2}\left(\frac{aL^2}{2} + \frac{bL^3}{3}\right)$

25. A particle of mass m moving in the x direction with speed $2v$ is hit by another particle of mass $2m$ moving in the y direction with speed v. If the collision is perfectly inelastic, the percentage loss in the energy during the collision is close to : **[2015]**

(a) 56% (b) 62%

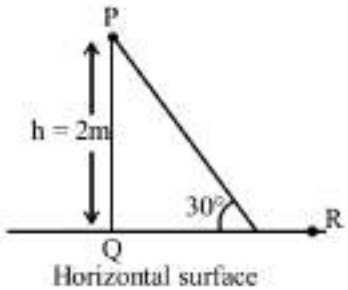
(c) 44% (d) 50%

26. A person trying to lose weight by burning fat lifts a mass of 10 kg upto a height of 1 m 1000 times. Assume that the potential energy lost each time he lowers the mass is dissipated. How much fat will he use up considering the work done only when the weight is lifted up? Fat supplies 3.8×10^7 J of energy per kg which is converted to mechanical energy with a 20% efficiency rate. Take $g = 9.8\ ms^{-2}$: **[2016]**

(a) 9.89×10^{-3} kg (b) 12.89×10^{-3} kg

(c) 2.45×10^{-3} kg (d) 46×10^4 J

27. A point particle of mass m, moves long the uniformly rough track PQR as shown in the figure. The coefficient of friction, between the particle and the rough track equals μ. The particle is released, from rest from the point P and it comes to rest at a point R. The energies, lost by the ball, over the parts, PQ and QR, of the track, are equal to each other, and no energy is lost when particle changes direction from PQ to QR. The value of the coefficient of friction μ and the distance x (= QR), are, respectively close to : **[2016]**



(a) 0.29 and 3.5 m (b) 0.29 and 6.5 m
(c) 0.2 and 6.5 m (d) 0.2 and 3.5 m

28. A body of mass m = 10^{-2} kg is moving in a medium and experiences a frictional force $F = -kv^2$. Its intial speed is $v_0 = 10\ ms^{-1}$. If, after 10 s, its energy is $\frac{1}{8}mv_0^2$, the value of k will be: **[2017]**

(a) 10^{-4} kg m^{-1} (b) 10^{-1} kg m^{-1} s^{-1}
(c) 10^{-3} kg m^{-1} (d) 10^{-3} kg s^{-1}

29. A time dependent force F = 6t acts on a particle of mass 1 kg. If the particle starts from rest, the work done by the force during the first 1 secand will be **[2017]**

(a) 9 J (b) 18 J
(c) 4.5 J (d) 22 J

30. A particle is moving in a circular path of radius a under the action of an attractive potential $U = -\frac{k}{2r^2}$. Its total energy is: **[2018]**

(a) $-\frac{k}{4a^2}$ (b) $\frac{k}{2a^2}$
(c) zero (d) $-\frac{3}{2}\frac{k}{a^2}$

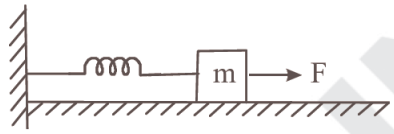
31. In a collinear collision, a particle with an initial speed v_0 strikes a stationary particle of the same mass. If the final total kinetic energy is 50% greater than the original kinetic energy, the magnitude of the relative velocity between the two particles, after collision, is: **[2018]**

(a) $\frac{v_0}{4}$ (b) $\sqrt{2}v_0$
(c) $\frac{v_0}{2}$ (d) $\frac{v_0}{\sqrt{2}}$

32. It is found that if a neutron suffers an elastic collinear collision with deuterium at rest, fractional loss of its energy is p_d; while for its similar collision with carbon nucleus at rest, fractional loss of energy is P_c. The values of P_d and P_c are respectively: **[2018]**

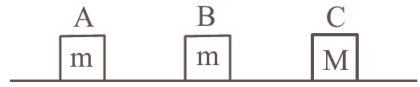
(a) (·89, ·28) (b) (·28, ·89)
(c) (0, 0) (d) (0, 1)

33. A block of mass m, lying on a smooth horizontal surface, is attached to a spring (of negligible mass) of spring constant *k*. The other end of the spring is fixed, as shown in the figure. The block is initally at rest in its equilibrium position. If now the block is pulled with a constant force F, the maximum speed of the block is: **[2019]**



(a) $\frac{2F}{\sqrt{mk}}$ (b) $\frac{F}{\pi\sqrt{mk}}$
(c) $\frac{\pi F}{\sqrt{mk}}$ (d) $\frac{F}{\sqrt{mk}}$

34. There block A, B and C are lying on a smooth horizontal surface, as shown in the figure. A and B have equal masses, m while C has mass M. Block A is given an inital speed *v* towards B due to which it collides with B perfectly inelastically. The combined mass collides with C, also perfectly inelastically $\frac{5}{6}$th of the initial kinetic energy is lost in whole process. What is value of M/m? **[2019]**



(a) 5 (b) 2
(c) 4 (d) 3

35. A uniform cable of mass 'M' and length 'L' is placed on a horizontal surface such that its $\left(\frac{1}{n}\right)^{th}$ part is hanging below the edge of the surface. To lift the hanging part of the cable upto the surface, the work done should be: **[2020]**

(a) $\frac{MgL}{2n^2}$ (b) $\frac{MgL}{n^2}$
(c) $\frac{2MgL}{n^2}$ (d) nMgL

36. A body of mass 2 kg makes an elastic collision with a second body at rest and continues to move in the original direction but with one fourth of its original speed. What is the mass of the second body? **[2020]**

(a) 1.0 kg (b) 1.5 kg
(c) 1.8 kg (d) 1.2 kg

Answer Key														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(c)	(d)	(b)	(b)	(c)	(b)	(b)	(b)	(a)	(b)	(b)	(b)	(d)	(b)	(b)
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
(a)	(b)	(d)	(c)	(d)	(a)	(c)	(d)	(c)	(a)	(b)	(a)	(a)	(c)	(c)
31	32	33	34	35	36									
(b)	(a)	(d)	(c)	(b)	(d)									

Solutions

1. **(c)** Kinetic energy of a system of particle is zero only when the speed of each particles is zero. This implies momentum of each particle is zero, thus linear momentum of the system of particle has to be zero.
Also if linear momentum of the system is zero it does not mean linear momentum of each particle is zero. This is because linear momentum is a vector quantity. In this case the kinetic energy of the system of particles will not be zero.
$\therefore$ A does not imply B but B implies A.
Given, force, $F = 200$ N extension of wire, $x = 1$mm.

2. **(d)** The elastic potential energy

$$= \frac{1}{2} \times \text{Force} \times \text{extension}$$

$$= \frac{1}{2} \times F \times x$$

$$= \frac{1}{2} \times 200 \times 0.001 = 0.1 \text{ J}$$

3. **(b)** Spring constant, $k = 5 \times 10^3$ N/m
Let x_1 and x_2 be the initial and final stretched position of the spring, then

Work done, $W = \frac{1}{2}k\left(x_2^2 - x_1^2\right)$

$$= \frac{1}{2} \times 5 \times 10^3 \left[(0.1)^2 - (0.05)^2\right]$$

$$= \frac{5000}{2} \times 0.15 \times 0.05 = 18.75 \text{ Nm}$$

4. **(b)** Power, $P = Fv = ma.v$

$$\Rightarrow \quad P = \frac{mdv}{dt} v = c = \text{contant}$$

$$\left(\because F = ma = \frac{mdv}{dt}\right)$$

$mv_0 v = cdt$
Integrating both sides, we get

$$m\int_0^v vdv = c\int_0^t dt$$

$$\Rightarrow \quad \frac{1}{2}mv^2 = ct$$

$$\Rightarrow \quad \frac{v^2}{2} = \frac{c.t}{m}$$

$$\Rightarrow \quad v_2 = \frac{2c.t}{m}$$

$$\Rightarrow \quad v = \sqrt{\frac{2c}{m}} \times t^{1/2}$$

$$\Rightarrow \quad \frac{dx}{dt} = \sqrt{\frac{2c}{m}} \times t^{1/2} \quad \text{where } v = \frac{dx}{dt}$$

$$\Rightarrow \quad \int_e^x dx = \sqrt{\frac{2c}{m}} \times \int_0^t t^{1/2} dt$$

$$\Rightarrow \quad x = \sqrt{\frac{2c}{m}} \times \frac{2t^{3/2}}{3} \quad \Rightarrow \quad x \propto t^{3/2}$$

5. **(c)** Given : retardation $\propto$ displacement
i.e., $a = -kx$ [Here, k = constant]

But $a = v\frac{dv}{dx}$

$$\therefore \frac{vdv}{dx} = -kx \Rightarrow \int_{v_1}^{v_2} v\, dv = -\int_0^x kxdx$$

$$\Rightarrow \quad \left[\frac{v^2}{2}\right]_{v_1}^{v_2} = -k\left[\frac{x^2}{2}\right]_0^x$$

$$\Rightarrow \quad \left(v_2^2 - v_1^2\right) = -\frac{kx^2}{2}$$

$$\Rightarrow \quad \frac{1}{2}m\left(v_2^2 - v_1^2\right) = \frac{1}{2}m\left(\frac{-kx^2}{2}\right)$$

$\therefore$ Loss in kinetic energy, $\therefore \Delta K \propto x^2$

6. (b) Mass of over hanging part of the chain

$m' = \frac{4}{2} \times (0.6)\text{kg} = 1.2 \text{ kg}$

Weight of hanging part of the chain

$= 1.2 \times 10 = 12 \text{ N}$

C.M. of hanging part = 0.3 m below the table

Workdone in putting the entire cha in on the table = 12 × 0.30 = 3.6 J.

7. (b) Given, Force, $\vec{F} = \left(5\hat{i} + 3\hat{j} + 2\hat{k}\right)$

Displacement, $x = \left(2\hat{i} - \hat{j}\right)$

Work done,

$W = \vec{F} \cdot \vec{x} = (5\hat{i} + 3\hat{j} + 2\hat{k}) \cdot (2\hat{i} - \hat{j})$

$= 10 - 3 = 7$ joules

8. (b) Let a be the acceleration of body

Using, $v = u + at$

$v_1 = 0 + at_1 \Rightarrow a = \frac{v_1}{t_1}$

Velocity of the body at instant t,

$v = at$

$\Rightarrow \quad v = \frac{v_1 t}{t_1}$

Instantaneous powr, $P = \vec{F} \cdot \vec{v} = (m\vec{a}) \cdot \vec{v}$

$= \left(\frac{mv_1}{t_1}\right)\left(\frac{v_1 t}{t_1}\right) = m\left(\frac{v_1}{t_1}\right)^2 t$

9. (a) Work done by such force is always zero since force is acting in a direction perpendicular to velocity.

$\therefore$ From work-energy theorem = $\Delta K = 0$

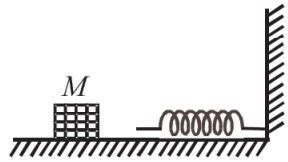
K remains constant.

10. (b) When the spring gets compressed by length L.

K.E. lost by mass M = P.E. stored in the compressed spring.

$\frac{1}{2}Mv^2 = \frac{1}{2}kL^2$

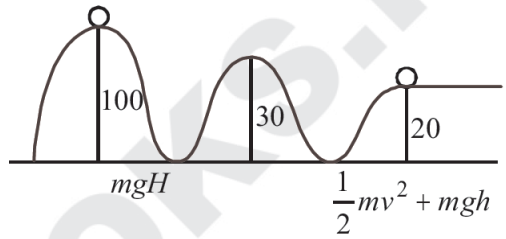
$\Rightarrow \quad v = \sqrt{\frac{k}{M}} \cdot L$



Momentum of the block, $= M \times v$

$= M \times \sqrt{\frac{k}{M}} \cdot L = \sqrt{kM} \cdot L$

11. (b)



Using conservation of energy,

Total energy at 100 m height

= Total energy at 20m height

$m(10 \times 100) = m\left(\frac{1}{2}v^2 + 10 \times 20\right)$

or $\frac{1}{2}v^2 = 800$ or $v = \sqrt{1600} = 40$ m/s

ALTERNATE SOLUTION

Loss in potential energy = gain in kinetic energy

$m \times g \times 80 = \frac{1}{2}mv^2$

$10 \times 80 = \frac{1}{2}v^2$

$v^2 = 1600$ or $v = 40$ m/s

12. (b) Using, $v = u + at$

$\Rightarrow \quad v = 0 + aT$

$\Rightarrow \quad a = \frac{V}{T}$

Force, $F = ma = \frac{mV}{T}$

Velocity acquired, $V = at = \frac{V}{T}t$

Instantaneous power, $P = Fv$

$\Rightarrow \quad P = \frac{mV}{T} \times \frac{V}{T}t = \frac{mv^2}{T^2}t$

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13. (d) Considering conservation of momentum along x-direction,

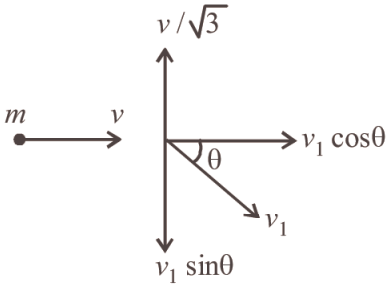
$mv = mv_1 \cos\theta$ ...(1)

where v_1 is the velocity of second mass

In y-direction,

$$0 = \frac{mv}{\sqrt{3}} - mv_1 \sin\theta$$

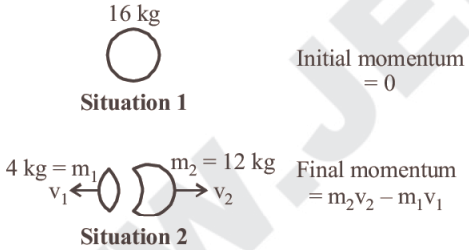
or $m_1 v_1 \sin\theta = \frac{mv}{\sqrt{3}}$ ...(2)



Squaring and adding eqns. (1) and (2) we get

$$v_1^2 = v^2 + \frac{v^2}{\sqrt{3}} \Rightarrow v_1 = \frac{2}{\sqrt{3}} v$$

14. (b) Let the velocity and mass of 4 kg piece be v_1 and m_1 and that of 12 kg piece be v_2 and m_2.



Applying conservation of linear momentum

$16 \times 0 = 4 \times v_1 + 12 \times 4$

$$\Rightarrow \quad v_1 = -\frac{12 \times 4}{4} = -12\ ms^{-1}$$

Kinetic energy of 4 kg mass

$$\therefore K.E. = \frac{1}{2} m_1 v_1^2 = \frac{1}{2} \times 4 \times 144 = 288\ J$$

15. (b) Given, Mass of the particle, $m = 100$g

Initial speed of the particle, $\mu = 5$ m/s

Final speed of the particle, $v = 0$

Work done by the force of gravity

= Loss in kinetic energy of the body.

$$= \frac{1}{2} m (v^2 - u^2) = \frac{1}{2} \times \frac{100}{1000} (0^2 - 5^2)$$

$= -1.25$ J

16. (a) Potential energy

$$V(x) = \frac{x^4}{4} - \frac{x^2}{2} \text{ joule}$$

For maxima of minima

$$\frac{dV}{dx} = 0 \Rightarrow x^3 - x = 0 \Rightarrow x = \pm 1$$

$$\Rightarrow \text{Min. P.E.} = \frac{1}{4} - \frac{1}{2} = -\frac{1}{4} \text{ J}$$

$\text{K.E.}_{(\text{max.})} + \text{P.E.}_{(\text{min.})} = 2$ (Given)

$$\therefore \text{K.E.}_{(\text{max.})} = 2 + \frac{1}{4} = \frac{9}{4}$$

$$\text{K.E.}_{\text{max.}} = \frac{1}{2} m v_{\text{max.}}^2$$

$$\Rightarrow \frac{1}{2} \times 1 \times v_{\text{max.}}^2 = \frac{9}{4} \Rightarrow v_{\text{max.}} = \frac{3}{\sqrt{2}}$$

17. (b) Suppose the spring gets compressed by x before stopping.

kinetic energy of the block = P.E. stored in the spring + work done against friction.

$$\Rightarrow \frac{1}{2} \times 2 \times (4)^2 = \frac{1}{2} \times 10{,}000 \times x^2 + 15 \times x$$

$$\Rightarrow 10{,}000\, x^2 + 30x - 32 = 0$$

$$\Rightarrow 5000x^2 + 15x - 16 = 0$$

$$\therefore \quad x = \frac{-15 \pm \sqrt{(15)^2 - 4 \times (5000)(-16)}}{2 \times 5000}$$

$= 0.055$m $= 5.5$cm.

18. (d) The average speed of the athelete

$$v = \frac{5}{t} = \frac{100}{10} = 10 \text{ m/s}$$

$$\therefore \quad \text{K.E.} = \frac{1}{2} m v^2$$

Assuming the mass of athelet to 40 kg his average K.E would be

$$\text{K.E} = \frac{1}{2} \times 40 \times (10)^2 = 2000 \text{J}$$

Assuming mass to 100 kg average kinetic energy

$$\text{K.E.} = \frac{1}{2} \times 100 \times (10)^2 = 5000 \text{J}$$

19. (c) Initial kinetic energy of the system

$$\text{K.E}_i = \frac{1}{2} m u^2 + \frac{1}{2} M (0)^2$$

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$$= \frac{1}{2} \times 0.5 \times 2 \times 2 + 0 = 1\text{J}$$

Momentum before collision

= Momentum after collision

$m_1u_1 + m_2u_2 = (m + M) \times v$

$\therefore 0.5 \times 2 + 1 \times 0 = (0.5 + 1) \times v \Rightarrow v = \frac{2}{3}\text{m/s}$

Final kinetic energy of the system is

$$\text{K.E}_f = \frac{1}{2}(m+M)v^2$$

$$= \frac{1}{2}(0.5+1) \times \frac{2}{3} \times \frac{2}{3} = \frac{1}{3}\text{J}$$

$\therefore$ Energy loss during collision

$$= \left(1 - \frac{1}{3}\right)\text{J} = 0.67\text{J}$$

20. (d) At equilibrium : $F = \frac{-dU(x)}{dx}$

$$\Rightarrow \quad F = \frac{-d}{dx}\left[\frac{a}{x^{12}} - \frac{b}{x^6}\right]$$

$$\Rightarrow \quad F = -\left[\frac{12a}{x^{13}} + \frac{6b}{x^7}\right]$$

$$\Rightarrow \quad \frac{12a}{x^{13}} = \frac{6b}{x^7} \quad \Rightarrow \quad x = \left(\frac{2a}{b}\right)^{\frac{1}{6}}$$

$\therefore \quad U_{\text{at equilibrium}} = \frac{a}{\left(\frac{2a}{b}\right)^2} - \frac{b}{\left(\frac{2a}{b}\right)} = -\frac{b^2}{4a}$ and

$U_{(x=\infty)} = 0$

$\therefore D = 0 - \left(-\frac{b^2}{4a}\right) = \frac{b^2}{4a}$

21. (a) In completely inelastic collision, all initial kinetic energy is not lost but loss in kinetic energy 15 as large as it can be. Linear momentum remain conserved in all types of collision. Statement -2 explains statement -1 correctly because applying the principle of conservation of momentum, we can get the common velocity and hence the kinetic energy of the combined body.

22. (c) K.E. $\propto t$

K.E. $= ct$ [Here, c = constant]

$$\Rightarrow \quad \frac{1}{2}mv^2 = ct$$

$$\Rightarrow \quad \frac{(mv)^2}{2m} = ct$$

$$\Rightarrow \quad \frac{p^2}{2m} = ct \quad (\because p = mv)$$

$$\Rightarrow \quad p = \sqrt{2\text{ctm}}$$

$$\Rightarrow \quad F = \frac{dp}{dt} = \frac{d\left(\sqrt{2ctm}\right)}{dt}$$

$$\Rightarrow \quad F = \sqrt{2\text{ cm}} \times \frac{1}{2\sqrt{t}}$$

$$\Rightarrow \quad F \propto \frac{1}{\sqrt{t}}$$

23. (d) Maximum energy loss $= \frac{\text{P}^2}{2\text{m}} - \frac{\text{P}^2}{2(\text{m}+\text{M})}$

$$\left[\because \text{K.E.} = \frac{\text{P}^2}{2\text{m}} = \frac{1}{2}\text{mv}^2\right]$$

$$= \frac{\text{P}^2}{2\text{m}}\left[\frac{\text{M}}{(\text{m}+\text{M})}\right] = \frac{1}{2}\text{mv}^2\left\{\frac{\text{M}}{\text{m}+\text{M}}\right\}$$

Statement II is a case of perfectly inelastic collision.

By comparing the equation given in statement I with above equation, we get

$$\text{f} = \left(\frac{\text{M}}{\text{m}+\text{M}}\right) \text{ instead of } \left(\frac{\text{m}}{\text{M}+\text{m}}\right)$$

Hence statement I is wrong and statement II is correct.

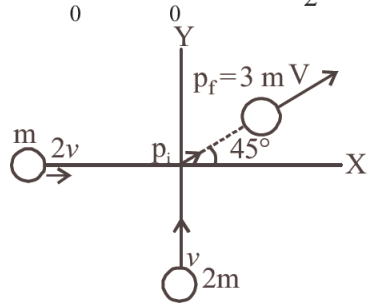
24. (c) Work done in stretching the rubber-band by a distance dx is

$dW = F\,dx = (ax + bx^2)dx$

Integrating both sides,

$$W = \int_0^L axdx + \int_0^L bx^2dx = \frac{aL^2}{2} + \frac{bL^3}{3}$$

25. (a)



Initial momentum of the system

$\text{p}_\text{i} = \sqrt{[\text{m}(2\text{V})^2 \times 2\text{m}(2\text{V})^2]}$

$= \sqrt{2}\text{m} \times 2\text{V}$

Final momentum of the system = 3mV
By the law of conservation of momentum

$$2\sqrt{2}mv = 3mV \Rightarrow \frac{2\sqrt{2}v}{3} = V_{combined}$$

Loss in energy

$$\Delta E = \frac{1}{2}m_1V_1^2 + \frac{1}{2}m_2V_2^2 - \frac{1}{2}(m_1+m_2)V_{combined}^2$$

$$DE = 3mv^2 - \frac{4}{3}mv^2 = \frac{5}{3}mv^2 = 55.55\%$$

Percentage loss in energy during the collision $\simeq$ 56%

26. (b) $n = \frac{W}{input} = \frac{mgh \times 1000}{input} = \frac{10 \times 9.8 \times 1 \times 1000}{input}$

$$\text{Input} = \frac{98000}{0.2} = 49 \times 10^4 J$$

$$\text{Fat used} = \frac{49 \times 10^4}{3.8 \times 10^7} = 12.89 \times 10^{-3} kg.$$

27. (a) Work done by friction at QR = μmgx

In triangle, $\sin 30° = \frac{1}{2} = \frac{2}{PQ}$

$\Rightarrow PQ = 4m$

Work done by friction at PQ = $\mu mg \times \cos 30° \times 4 = \mu mg \times \frac{\sqrt{3}}{2} \times 4 = 2\sqrt{3}\ \mu mg$

Since work done by friction on parts PQ and QR are equal,

$\mu mg\, x = 2\sqrt{3}\ umg$

$\Rightarrow x = 2\sqrt{3} \cong 3.5m$

Using work energy theorem mg sin 30° × 4

$= 2\sqrt{3}\ \mu mg + \mu mgx$

$\Rightarrow 2 = 4\sqrt{3}\ \mu$

$\Rightarrow \mu = 0.29$

28. (a) Let V_f is the final speed of the body.
From questions,

$$\frac{1}{2}mV_f^2 = \frac{1}{8}mV_0^2 \quad \Rightarrow \quad V_f = \frac{V_0}{2} = 5\,m/s$$

$$F = m\left(\frac{dV}{dt}\right) = -kV^2 \quad \therefore \quad (10^{-2})\frac{dV}{dt} = -kV^2$$

$$\int_{10}^{5}\frac{dV}{V^2} = -100K\int_0^{10} dt$$

$$\frac{1}{5} - \frac{1}{10} = 100K(10) \qquad \text{or,} \quad K = 10^{-4}\ kgm^{-1}$$

29. (c) Using, $F = ma = m\frac{dV}{dt}$

$$6t = 1.\frac{dV}{dt} \qquad [\because \ m = 1 \text{ kg given}]$$

$$\int_0^v dV = \int 6t\,dt \quad V = 6\left[\frac{t^2}{2}\right]_0^1 = 3\,ms^{-1}$$

$[\because \ t = 1 \text{ sec given}]$

From work-energy theorem,

$$W = \Delta KE = \frac{1}{2}m\left(V^2 - u^2\right) = \frac{1}{2} \times 1 \times 9 = 4.5\ J$$

30. (c) $F = -\frac{\partial u}{\partial r}\hat{r} = \frac{K}{r^3}\hat{r}$

Since particle is moving in circular path

$$F = \frac{mv^2}{r} = \frac{K}{r^3} \Rightarrow mv^2 = \frac{K}{r^2}$$

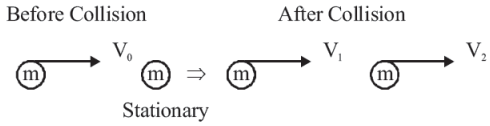
$$\therefore \ K.E. = \frac{1}{2}mv^2 = \frac{K}{2r^2}$$

Total energy = P.E. + K.E.

$$= -\frac{K}{2r^2} + \frac{K}{2r^2} = \text{Zero}$$

$$\left(\because P.E. = -\frac{K}{2r^2} \text{ given}\right)$$

31. (b)



$$\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 = \frac{3}{2}\left(\frac{1}{2}mv_0^2\right)$$

$$\Rightarrow \ v_1^2 + v_2^2 = \frac{3}{2}v_0^2 \qquad ....(i)$$

From momentum conservation

$mv_0 = m(v_1 + v_2)$ ....(ii)

Squarring both sides,

$(v_1 + v_2)^2 = v_0^2$

$\Rightarrow \ v_1^2 + v_2^2 + 2v_1v_2 = v_0^2$

$$2v_1v_2 = -\frac{v_0^2}{2}$$

$$(v_1 - v_2)^2 = v_1^2 + v_2^2 - 2v_1v_2 = \frac{3}{2}v_0^2 + \frac{v_0^2}{2}$$

Solving we get relative velocity between the two particles

$v_1 - v_2 = \sqrt{2}v_0$

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32. (a) For collision of neutron with deuterium:

Applying conservation of momentum :

$mv + 0 = mv_1 + 2mv_2$ .....(i)

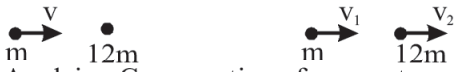
$v_2 - v_1 = v$ .....(ii)

$\because$ Collision is elastic, e = 1

From eqn (i) and eqn (ii) $v_1 = -\frac{v}{3}$

$$P_d = \frac{\frac{1}{2}mv^2 - \frac{1}{2}mv_1^2}{\frac{1}{2}mv^2} = \frac{8}{9} = 0.89$$

Now, For collision of neutron with carbon nucleus



Applying Conservation of momentum

$mv + 0 = mv_1 + 12mv_2$ ....(iii)

$v = v_2 - v_1$ ....(iv)

From eqn (iii) and eqn (iv)

$$v_1 = -\frac{11}{13}v$$

$$P_c = \frac{\frac{1}{2}mv^2 - \frac{1}{2}m\left(\frac{11}{13}v\right)^2}{\frac{1}{2}mv^2} = \frac{48}{169} \approx 0.28$$

33. (d) Maximum speed is at equilibrium position where

$$F = kx \Rightarrow x = \frac{F}{k}$$

From work-energy theorem,

$$W_F + W_{sp} = \Delta KE$$

$$F(x) - \frac{1}{2}kx^2 = \frac{1}{2}mv^2 - 0$$

$$F\left(\frac{F}{k}\right) - \frac{1}{2}k\left(\frac{F}{k}\right)^2 = \frac{1}{2}mv^2$$

$$\Rightarrow \frac{1}{2}\frac{F^2}{K} = \frac{1}{2}mv^2$$

or, $v_{max} = \frac{F}{\sqrt{mk}}$

34. (c) Kinetic energy of block A

$$k_1 = \frac{1}{2}mv_0^2$$

$\therefore$ From principle of linear momentum conservation

$$mv_0 = (2m + M)v_f \Rightarrow v_f = \frac{mv_0}{2m + M}$$

$$K.E_f = \frac{1}{6}K.E_i \quad \text{(given)}$$

$$\frac{1}{2}(2m + M)v_f^2 = \frac{1}{6} \times \frac{1}{2}mv_0^2$$

$$6(2m + M)\frac{m^2v_0^2}{(2m + M)^2} = mv_0^2$$

$\Rightarrow 6m = 2m + M$

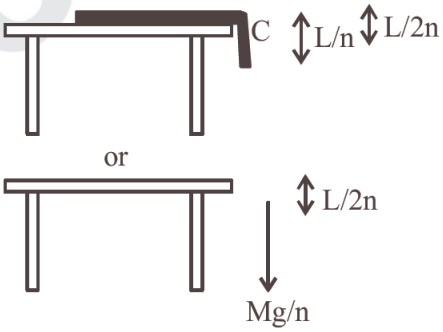
$\Rightarrow 4m = M$

35. (b) Length of hanging part = L/n

Mass of hanging part = M/n

Weight of hanging part = Mg/n

Let 'C' be the centre of mass of the hanging part.



The hanging part can be assumed to be a particle of weight Mg/n at a distance L/n below the table top. The work done in lifting it to the table top is equal to increase in its potential energy.

$$\therefore W = \left(\frac{Mg}{n}\right)\left(\frac{L}{n}\right)$$

$$\therefore W = \frac{MgL}{n^2}$$

36. (d) For head on elastic collision we have

$$V_1 = \frac{(m_1 - m_2)u_1}{m_1 + m_2} + \frac{2m_2u_2}{m_1 + m_2}$$

Here $m_1 = 2$kg, $u_1 = x$, $u_2 = 0$,

$v_1 = x/4$

$$\therefore \frac{x}{4} = \frac{(2 - m_2)x}{2 + m_2} \Rightarrow m_2 = 1.2\text{kg}$$

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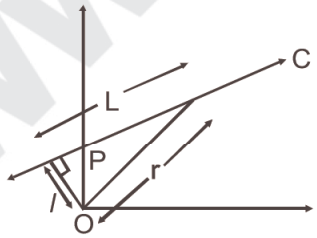
6 System of Particles and Rotational Motion

1. Initial angular velocity of a circular disc of mass M is ω_1. Then two small spheres of mass m are attached gently to diametrically opposite points on the edge of the disc. What is the final angular velocity of the disc? **[2002]**
   (a) $\left(\frac{M+m}{M}\right)\omega_1$ (b) $\left(\frac{M+m}{m}\right)\omega_1$
   (c) $\left(\frac{M}{M+4m}\right)\omega_1$ (d) $\left(\frac{M}{M+2m}\right)\omega_1$.
2. Two identical particles move towards each other with velocity $2v$ and v respectively. The velocity of centre of mass is **[2002]**
   (a) v (b) $v/3$
   (c) $v/2$ (d) zero
3. Moment of inertia of a circular wire of mass M and radius R about its diameter is **[2002]**
   (a) $MR^2/2$ (b) MR^2
   (c) $2MR^2$ (d) $MR^2/4$.
4. A particle of mass m moves along line PC with velocity v as shown. What is the angular momentum of the particle about P? **[2002]**



   (a) mvL (b) mvl
   (c) mvr (d) zero.
5. A circular disc X of radius R is made from an iron plate of thickness t, and another disc Y of radius $4R$ is made from an iron plate of thickness $\frac{t}{4}$. Then the relation between the moment of inertia I_X and I_Y is **[2003]**
   (a) $I_Y = 32\, I_X$ (b) $I_Y = 16\, I_X$
   (c) $I_Y = I_X$ (d) $I_Y = 64\, I_X$
6. A particle performing uniform circular motion has angular frequency is doubled & its kinetic energy halved, then the new angular momentum is **[2003]**
   (a) $\frac{L}{4}$ (b) $2L$
   (c) $4L$ (d) $\frac{L}{2}$
7. Let $\vec{F}$ be the force acting on a particle having position vector $\vec{r}$, and $\vec{T}$ be the torque of this force about the origin. Then **[2003]**
   (a) $\vec{r}.\vec{T} = 0$ and $\vec{F}.\vec{T} \neq 0$
   (b) $\vec{r}.\vec{T} \neq 0$ and $\vec{F}.\vec{T} = 0$
   (c) $\vec{r}.\vec{T} \neq 0$ and $\vec{F}.\vec{T} \neq 0$
   (d) $\vec{r}.\vec{T} = 0$ and $\vec{F}.\vec{T} = 0$
8. A solid sphere is rotating in free space. If the radius of the sphere is increased keeping mass same, which one of the following will not be affected ? **[2004]**
   (a) Angular velocity
   (b) Angular momentum
   (c) Moment of inertia
   (d) Rotational kinetic energy
9. One solid sphere A and another hollow sphere B are of same mass and same outer radii. Their moment of inertia about their diameters are respectively I_A and I_B such that **[2004]**
   (a) $I_A < I_B$ (b) $I_A > I_B$
   (c) $I_A = I_B$ (d) $\frac{I_A}{I_B} = \frac{d_A}{d_B}$
   where d_A and d_B are their densities.

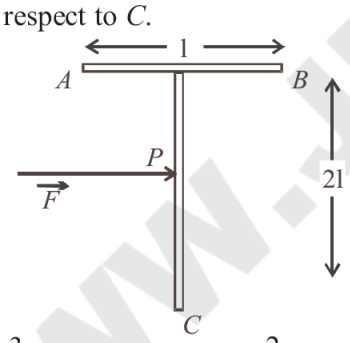
10. A body A of mass M while falling vertically downwards under gravity breaks into two parts; a body B of mass $\frac{1}{3}M$ and a body C of mass $\frac{2}{3}M$. The centre of mass of bodies B and C taken together shifts compared to that of body A towards **[2005]**

(a) does not shift
(b) depends on height of breaking
(c) body B
(d) body C

11. The moment of inertia of a uniform semicircular disc of mass M and radius r about a line perpendicular to the plane of the disc through the centre is **[2005]**

(a) $\frac{2}{5}Mr^2$ (b) $\frac{1}{4}Mr$
(c) $\frac{1}{2}Mr^2$ (d) Mr^2

12. A 'T' shaped object with dimensions shown in the figure, is lying on a smooth floor. A force '$\vec{F}$' is applied at the point P parallel to AB, such that the object has only the translational motion without rotation. Find the location of P with respect to C. **[2005]**



(a) $\frac{3}{2}\ell$ (b) $\frac{2}{3}\ell$
(c) ℓ (d) $\frac{4}{3}\ell$

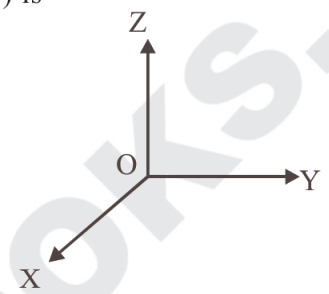
13. Consider a two particle system with particles having masses m_1 and m_2. If the first particle is pushed towards the centre of mass through a distance d, by what distance should the second particle is moved, so as to keep the centre of mass at the same position? **[2006]**

(a) $\frac{m_2}{m_1}d$ (b) $\frac{m_1}{m_1+m_2}d$
(c) $\frac{m_1}{m_2}d$ (d) d

14. Four point masses, each of value m, are placed at the corners of a square $ABCD$ of side ℓ. The moment of inertia of this system about an axis passing through A and parallel to BD is **[2006]**

(a) $2m\ell^2$ (b) $\sqrt{3}m\ell^2$
(c) $3m\ell^2$ (d) $m\ell^2$

15. A force of $-F\hat{k}$ acts on O, the origin of the coordinate system. The torque about the point (1, –1) is **[2006]**



(a) $F(\hat{i}-\hat{j})$ (b) $-F(\hat{i}+\hat{j})$
(c) $F(\hat{i}+\hat{j})$ (d) $-F(\hat{i}-\hat{j})$

16. A thin circular ring of mass m and radius R is rotating about its axis with a constant angular velocity ω. Two objects each of mass M are attached gently to the opposite ends of a diameter of the ring. The ring now rotates with an angular velocity $\omega' =$ **[2006]**

(a) $\frac{\omega(m+2M)}{m}$ (b) $\frac{\omega(m-2M)}{(m+2M)}$
(c) $\frac{\omega m}{(m+M)}$ (d) $\frac{\omega m}{(m+2M)}$

17. A circular disc of radius R is removed from a bigger circular disc of radius $2R$ such that the circumferences of the discs coincide. The centre of mass of the new disc is α / R form the centre of the bigger disc. The value of α is **[2007]**

(a) 1/4 (b) 1/3
(c) 1/2 (d) 1/6

18. A round uniform body of radius R, mass M and moment of inertia I rolls down (without slipping) an inclined plane making an angle θ with the horizontal. Then its acceleration is **[2007]**

(a) $\frac{g\sin\theta}{1-MR^2/I}$ (b) $\frac{g\sin\theta}{1+I/MR^2}$
(c) $\frac{g\sin\theta}{1+MR^2/I}$ (d) $\frac{g\sin\theta}{1-I/MR^2}$

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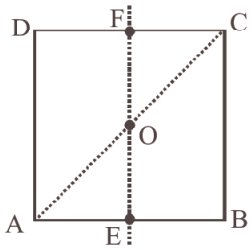
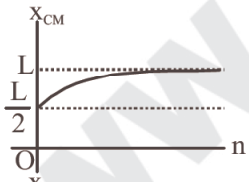
19. Angular momentum of the particle rotating with a central force is constant due to **[2007]**
(a) constant torque
(b) constant force
(c) constant linear momentum
(d) zero torque

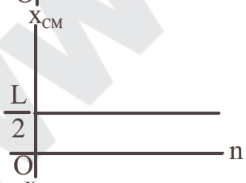
20. For the given uniform square lamina *ABCD*, whose centre is *O*, **[2007]**

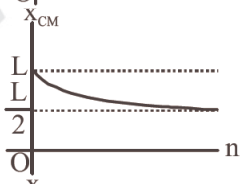


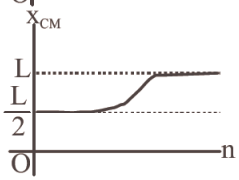
(a) $I_{AC} = \sqrt{2}\, I_{EF}$ (b) $\sqrt{2} I_{AC} = I_{EF}$
(c) $I_{AD} = 3I_{EF}$ (d) $I_{AC} = I_{EF}$

21. A thin rod of length '*L*' is lying along the *x*-axis with its ends at $x = 0$ and $x = L$. Its linear density (mass/length) varies with *x* as $k\left(\frac{x}{L}\right)^n$, where n can be zero or any positive number. If the position x_{CM} of the centre of mass of the rod is plotted against '*n*', which of the following graphs best approximates the dependence of x_{CM} on *n*? **[2008]**

(a)


(b)


(c)


(d)


22. Consider a uniform square plate of side '*a*' and mass '*M*'. The moment of inertia of this plate about an axis perpendicular to its plane and passing through one of its corners is **[2008]**

(a) $\frac{5}{6}Ma^2$ (b) $\frac{1}{12}Ma^2$
(c) $\frac{7}{12}Ma^2$ (d) $\frac{2}{3}Ma^2$

23. A thin uniform rod of length *l* and mass *m* is swinging freely about a horizontal axis passing through its end. Its maximum angular speed is ω. Its centre of mass rises to a maximum height of **[2009]**

(a) $\frac{1}{6}\frac{l\omega}{g}$ (b) $\frac{1}{2}\frac{l^2\omega^2}{g}$
(c) $\frac{1}{6}\frac{l^2\omega^2}{g}$ (d) $\frac{1}{3}\frac{l^2\omega^2}{g}$

24. A mass *m* hangs with the help of a string wrapped around a pulley on a frictionless bearing. The pulley has mass *m* and radius *R*. Assuming pulley to be a perfect uniform circular disc, the acceleration of the mass *m*, if the string does not slip on the pulley, is: **[2011]**

(a) g (b) $\frac{2}{3}g$
(c) $\frac{g}{3}$ (d) $\frac{3}{2}g$

25. A thin horizontal circular disc is rotating about a vertical axis passing through its centre. An insect is at rest at a point near the rim of the disc. The insect now moves along a diameter of the disc to reach its other end. During the journey of the insect, the angular speed of the disc. **[2011]**
(a) continuously decreases
(b) continuously increases
(c) first increases and then decreases
(d) remains unchanged

26. A pulley of radius 2 m is rotated about its axis by a force $F = (20t - 5t^2)$ newton (where *t* is measured in seconds) applied tangentially. If the moment of inertia of the pulley about its axis of rotation is 10 kg-m^2 the number of

rotations made by the pulley before its direction of motion is reversed, is: **[2011]**

(a) more than 3 but less than 6
(b) more than 6 but less than 9
(c) more than 9
(d) less than 3

27. A loop of radius r and mass m rotating with an angular velocity ω_0 is placed on a rough horizontal surface. The initial velocity of the centre of the loop is zero. What will be the velocity of the centre of the loop when it ceases to slip? **[2013]**

(a) $\frac{r\omega_0}{4}$ (b) $\frac{r\omega_0}{3}$
(c) $\frac{r\omega_0}{2}$ (d) $r\omega_0$

28. A bob of mass m attached to an inextensible string of length l is suspended from a vertical support. The bob rotates in a horizontal circle with an angular speed ω rad/s about the vertical. About the point of suspension: **[2014]**

(a) angular momentum is conserved.
(b) angular momentum changes in magnitude but not in direction.
(c) angular momentum changes in direction but not in magnitude.
(d) angular momentum changes both in direction and magnitude.

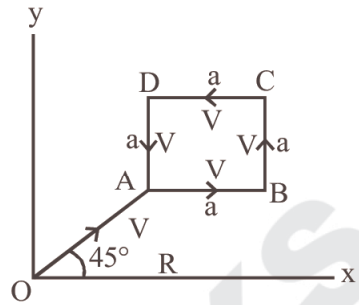
29. Distance of the centre of mass of a solid uniform cone from its vertex is z_0. If the radius of its base is R and its height is h then z_0 is equal to : **[2015]**

(a) $\frac{5h}{8}$ (b) $\frac{3h^2}{8R}$
(c) $\frac{h^2}{4R}$ (d) $\frac{3h}{4}$

30. From a solid sphere of mass M and radius R a cube of maximum possible volume is cut. Moment of inertia of cube about an axis passing through its center and perpendicular to one of its faces is:

(a) $\frac{4MR^2}{9\sqrt{3}\pi}$ (b) $\frac{4MR^2}{3\sqrt{3}\pi}$ **[2015]**
(c) $\frac{MR^2}{32\sqrt{2}\pi}$ (d) $\frac{MR^2}{16\sqrt{2}\pi}$

31. A particle of mass m is moving along the side of a square of side 'a', with a uniform speed v in the x-y plane as shown in the figure : **[2016]**



Which of the following statements is false for the angular momentum $\vec{L}$ about the origin?

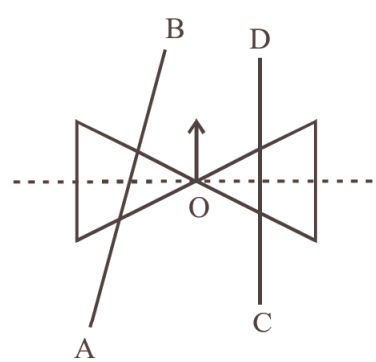
(a) $\vec{L} = mv\left[\frac{R}{\sqrt{2}} + a\right]\hat{k}$ when the particle is moving from B to C.

(b) $\vec{L} = \frac{mv}{\sqrt{2}}R\hat{k}$ when the particle is moving from D to A.

(c) $\vec{L} = -\frac{mv}{\sqrt{2}}R\hat{k}$ when the particle is moving from A to B.

(d) $\vec{L} = mv\left[\frac{R}{\sqrt{2}} - a\right]\hat{k}$ when the particle is moving from C to D.

32. A roller is made by joining together two cones at their vertices O. It is kept on two rails AB and CD, which are placed asymmetrically (see figure), with its axis perpendicular to CD and its centre O at the centre of line joining AB and CD (see figure). It is given a light push so that it starts rolling with its centre O moving parallel to CD in the direction shown. As it moves, the roller will tend to : **[2016]**



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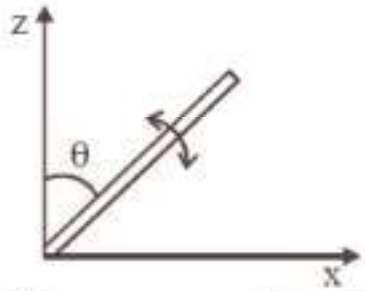
(a) go straight.
(b) turn left and right alternately.
(c) turn left.
(d) turn right.

33. The moment of inertia of a uniform cylinder of length ℓ and radius R about its perpendicular bisector is I. What is the ratio ℓ/R such that the moment of inertia is minimum? **[2017]**

(a) 1 (b) $\frac{3}{\sqrt{2}}$

(c) $\sqrt{\frac{3}{2}}$ (d) $\frac{\sqrt{3}}{2}$

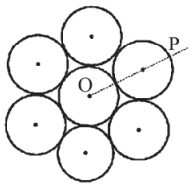
34. A slender uniform rod of mass M and length ℓ is pivoted at one end so that it can rotate in a vertical plane (see figure). There is negligible friction at the pivot. The free end is held vertically above the pivot and then released. The angular acceleration of the rod when it makes an angle θ with the vertical is **[2017]**



(a) $\frac{3g}{2\ell}\cos\theta$ (b) $\frac{2g}{3\ell}\cos\theta$

(c) $\frac{3g}{2\ell}\sin\theta$ (d) $\frac{2g}{2\ell}\sin\theta$

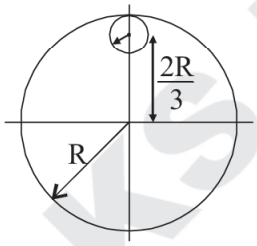
35. Seven identical circular planar disks, each of mass M and radius R are welded symmetrically as shown. The moment of inertia of the arrangement about the axis normal to the plane and passing through the point P is: **[2018]**



(a) $\frac{19}{2}MR^2$ (b) $\frac{55}{2}MR^2$

(c) $\frac{73}{2}MR^2$ (d) $\frac{181}{2}MR^2$

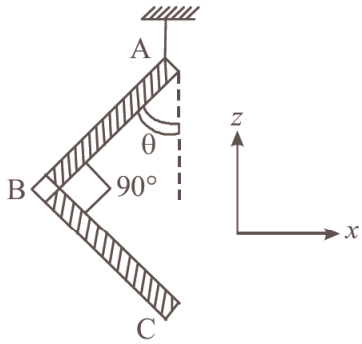
36. From a uniform circular disc of radius R and mass 9 M, a small disc of radius $\frac{R}{3}$ is removed as shown in the figure. The moment of inertia of the remaining disc about an axis perpendicular to the plane of the disc and passing, through centre of disc is : **[2018]**



(a) $4\ MR^2$ (b) $\frac{40}{9}MR^2$

(c) $10\ MR^2$ (d) $\frac{37}{9}MR^2$

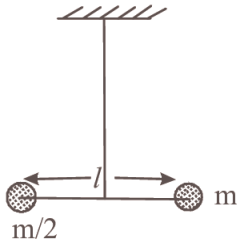
37. An L-shaped object, made of thin rods of uniform mass density, is suspended with a string as shown in figure. If AB = BC, and the angle made by AB with downward vertical is θ, then: **[2019]**



(a) $\tan\theta = \frac{1}{2\sqrt{3}}$ (b) $\tan\theta = \frac{1}{2}$

(c) $\tan\theta = \frac{2}{\sqrt{3}}$ (d) $\tan\theta = \frac{1}{3}$

38. Two masses m and $\frac{m}{2}$ are connected at the two ends of a massless rigid rod of length *l*. The rod is suspended by a thin wire of torsional constant *k* at the centre of mass of the rod-mass system (see figure). Because of torsional constant *k*, the restoring toruque is $\tau = k\theta$ for angular displacement θ. If the rod is rotated by θ_0 and released, the tension in it when it passes through its mean position will be: **[2019]**



(a) $\frac{3k\theta_0^2}{l}$ (b) $\frac{2k\theta_0^2}{l}$

(c) $\frac{k\theta_0^2}{l}$ (d) $\frac{k\theta_0^2}{2l}$

39. A stationary horizontal disc is free to rotate about its axis. When a torque is applied on it, its kinetic energy as a function of θ, where θ is the angle by which it has rotated, is given as $k\theta^2$. If its moment of inertia is I then the angular acceleration of the disc is **[2019]**

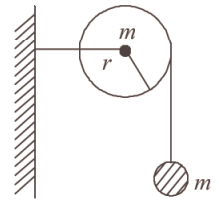
(a) $\frac{k}{4I}\theta$ (b) $\frac{k}{I}\theta$ (c) $\frac{k}{2I}\theta$ (d) $\frac{2k}{I}\theta$

40. The following bodies are made to roll up (without slipping) the same inclined plane from a horizontal plane : (i) a ring of radius R, (ii) a solid cylinder of radius $\frac{R}{2}$ and (iii) a solid sphere of radius $\frac{R}{4}$. If, in each case, the speed of the center of mass at the bottom of the incline is same, the ratio of the maximum heights they climb is : **[2019]**

(a) 4 : 3 : 2 (b) 10 : 15 : 7

(c) 14 : 15 : 20 (d) 2 : 3 : 4

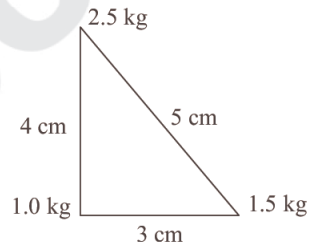
41. A s shown in the figure, a bob of mass *m* is tied by a massless string whose other end portion is wound on a fly wheel (disc) of radius r and mass m. When released from rest the bob starts falling vertically. When it has covered a distance of *h*, the angular speed of the wheel will be: **[2020]**



(a) $\frac{1}{r}\sqrt{\frac{4gh}{3}}$ (b) $r\sqrt{\frac{3}{2gh}}$

(c) $\frac{1}{r}\sqrt{\frac{2gh}{3}}$ (d) $r\sqrt{\frac{3}{4gh}}$

42. Three point particles of masses 1.0 kg, 1.5 kg and 2.5 kg are placed at three corners of a right angle triangle of sides 4.0 cm, 3.0 cm and 5.0 cm as shown in the figure. The center of mass of the system is at a point: **[2020]**



(a) 0.6 cm right and 2.0 cm above 1 kg mass

(b) 1.5 cm right and 1.2 cm above 1 kg mass

(c) 2.0 cm right and 0.9 cm above 1 kg mass

(d) 0.9 cm right an d 2.0 cm above 1 kg mass

43. The radius of gyration of a uniform rod of length *l*, about an axis passing through a point $\frac{l}{4}$ away from the centre of the rod, and perpendicular to it, is: **[2020]**

(a) $\frac{1}{4}l$ (b) $\frac{1}{8}l$

(c) $\sqrt{\frac{7}{48}}l$ (d) $\sqrt{\frac{3}{8}}l$

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(c)	(c)	(a)	(d)	(d)	(a)	(d)	(b)	(a)	(a)	(c)	(d)	(c)	(c)	(c)
16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
(d)	(b)	(b)	(d)	(d)	(a)	(d)	(c)	(b)	(c)	(a)	(c)	(c)	(d)	(a)
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**		
(a)	(c)	(c)	(c)	(d)	(a)	(d)	(c)	(d)	(c)	(a)	(d)	(c)		

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Solutions

1. **(c)** Moment of inertia of circular disc

$$I_1 = \frac{1}{2}MR^2$$

When two small sphere are attached on the edge of the disc, the moment of inertia becomes

$$I_2 = \frac{1}{2}MR^2 + 2mR^2$$

When two small spheres of mass m are attached gently, the external torque, about the axis of rotation, is zero and therefore the angular momentum about the axis of rotation is constant.

$$\therefore\ I_1\omega_1 = I_2\omega_2 \Rightarrow \omega_2 = \frac{I_1}{I_2}\omega_1$$

$$\therefore \omega_2 = \frac{\frac{1}{2}MR^2}{\frac{1}{2}MR^2 + 2mR^2} \times \omega_1 = \frac{M}{M+4m}\omega_1$$

2. **(c)** The velocity of centre of mass of two particle system is given by

$$v_c = \frac{m_1v_1 + m_2v_2}{m_1 + m_2}$$

Here, $m_1 = m_2 = m$
and $v_1 = 2v$ and $v_2 = -v$

$$\therefore v_{cm} = \frac{m(2v) + m(-v)}{m+m} = \frac{v}{2}$$

3. **(a)** M. I of a circular wire about an axis mm' passing through the centre of the circle and perpendicular to the plane of the circle $= MR^2$

As shown in the figure, X-axis and Y-axis lie along diameter of the ring . Using perpendicular axis theorem

$I_X + I_Y = I_Z$

Here, I_X and I_Y are the moment of inertia about the diameter.

$\Rightarrow 2\,I_X = MR^2$ [$\because I_X = I_Y$ (by symmetry) and $I_Z = MR^2$]

$$\therefore I_X = \frac{1}{2}MR^2$$

4. **(d)** Angular momentum (L)
= (linear momentum) × (perpendicular distance of the line of action of momentum from the axis of rotation)

As the particle moves with velocity V along line PC, the line of motion passes through P.

$\therefore$ L $= mv \times r$
$= mv \times 0$
$= 0$

5. **(d)** We know that density $(d) = \dfrac{mass(M)}{volume(V)}$

$$\therefore\ M = d \times V = d \times (\pi R^2 \times t).$$

The moment of inertia of a disc is given by

$$I = \frac{1}{2}MR^2$$

$$\therefore\ I_x = \frac{1}{2}MxR_x^2 = \frac{1}{2}(d \times \pi R^2 \times t)R^2$$

$$= \frac{\pi d}{2}t \times R^4$$

$$I_y = \frac{1}{2}M_yR_y^2 = \frac{1}{2}\left[\pi\left(4R^2\right)\left(\frac{1}{4}\right)d\right] \times (4R)^2$$

$$\therefore\ \frac{I_X}{I_Y} = \frac{t_XR_X^4}{t_YR_Y^4} = \frac{t \times R^4}{\frac{t}{4} \times (4R)^4} = \frac{1}{64}$$

6. **(a)** Rotational kinetic energy $= \dfrac{1}{2}I\omega^2$,

Angular momentum, $L = I\omega \Rightarrow I = \dfrac{L}{\omega}$

$$\therefore\ K.E. = \frac{1}{2}\frac{L}{\omega} \times \omega^2 = \frac{1}{2}L\omega$$

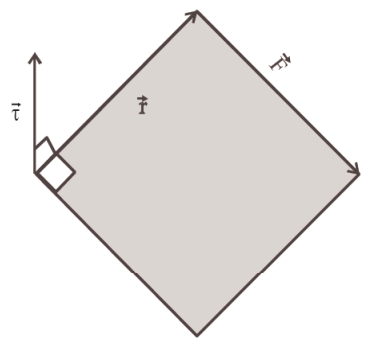
$$L' = \frac{2K.E}{\omega}$$

When ω is doubled and K.E is haled.
New angular momentum,

$$L' = \frac{\frac{2K.E}{2}}{2\omega}$$

$$\Rightarrow \therefore\ L' = \frac{L}{4}$$

7. **(d)** We know that $\vec{\tau} = \vec{r} \times \vec{F}$



Vector $\vec{\tau}$ is perpendicular to both $\vec{r}$ and $\vec{F}$. We also know that the dot product of two vectors which have an angle of 90° between them is zero.

$\therefore\ \vec{r} \cdot \vec{T} = 0$ and $\vec{F} \cdot \vec{T} = 0$

8. **(b)** Angular momentum will remain the same since no external torque act in free space.

9. **(a)** The moment of inertia of solid sphere A about its diameter $I_A = \frac{2}{5}MR^2$.

The moment of inertia of a hollow sphere B about its diameter $I_B = \frac{2}{3}MR^2$.

$\therefore I_A < I_B$

10. **(a)** The centre of mass of bodies B and C taken together does not shift as no external force acts. The centre of mass of the system continues its original path. It is only the internal forces which comes into play while breaking.

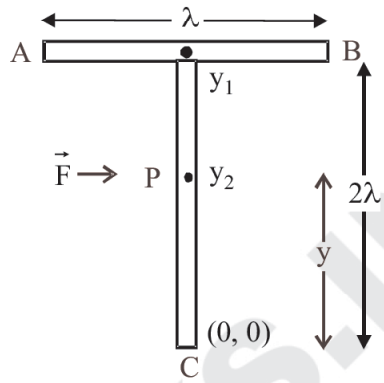
11. **(c)** The disc may be assumed as combination of two semi circular parts. Therefore, circular disc will have twice the mass of semicircular disc.

Moment of inertia of disc = $\frac{1}{2}(2m)r^2 = Mr^2$

Let I be the moment of inertia of the uniform semicircular disc

$\Rightarrow 2I = 2Mr^2 \Rightarrow I = \frac{Mr^2}{2}$

12. **(d)**

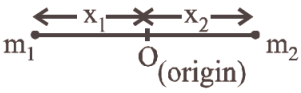


To have translational motion without rotation, the force $\vec{F}$ has to be applied at centre of mass. i.e. the point 'P' has to be at the centre of mass

Taking point C at the origin position, positions of y, and y_2 are $r_1 = 2l$, $r_2 = l$ and $ml = m$ and $m_2 = 2m$

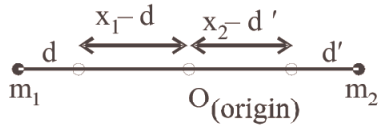
$$y = \frac{m_1 y_1 + m_2 y_2}{m_1 + m_2} = \frac{m \times 2\ell + 2m \times \ell}{3m} = \frac{4\ell}{3}$$

13. **(c)** Initially,



$$0 = \frac{m_1(-x_1) + m_2 x_2}{m_1 + m_2} \Rightarrow m_1 x_1 = m_2 x_2 \quad ...(1)$$

Let the particles is displaced through distanced away from centre of mass

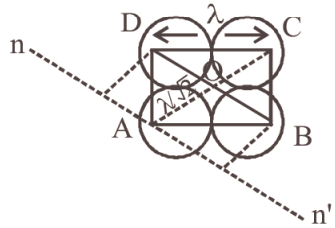


$$\therefore 0 = \frac{m_1(d - x_1) + m_2(x_2 - d')}{m_1 + m_2}$$

$$\Rightarrow 0 = m_1 d - m_1 x_1 + m_2 x_2 - m_2 d'$$

$$\Rightarrow d' = \frac{m_1}{m_2} d \qquad \text{[From (1).]}$$

14. **(c)**



$I_{nn'}$ = $M.I$ due to the point mass at B + $M.I$ due to the point mass at D + $M.I$ due to the point mass at C.

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$$I_{nn'} = m\left(\frac{\ell}{\sqrt{2}}\right)^2 + m\left(\frac{\ell}{\sqrt{2}}\right)^2 + m\left(\sqrt{2}\ell\right)^2$$

$$\Rightarrow I_{nn'} = 2\times m\left(\frac{\ell}{\sqrt{2}}\right)^2 + m(\sqrt{2}\ell)^2$$

$$= m\ell^2 + 2m\ell^2 = 3m\ell^2$$

15. (c) Torque $\vec{\tau} = \vec{r}\times\vec{F} = (\hat{i}-\hat{j})\times(-F\hat{k})$

$$= F[-\hat{i}\times\hat{k} + \hat{j}\times\hat{k}]$$

$$= F(\hat{j}+\hat{i}) = F(\hat{i}+\hat{j})$$

$$\left[\text{Since } \hat{k}\times\hat{i} = \hat{j} \text{ and } \hat{j}\times\hat{k} = \hat{i}\right]$$

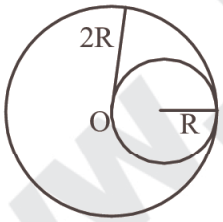
16. (d) Applying conservation of angular momentum $I'\omega' = I\omega$

$(mR^2 + 2MR^2)\omega' = mR^2\omega$

$\Rightarrow (m + 2m)R^2\omega' = mR^2\omega$

$$\Rightarrow \omega' = \omega\left[\frac{m}{m+2M}\right]$$

17. (b) Let σ be the mass per unit area of the disc. Then the mass of the complete disc $= \sigma(\pi(2R)^2)$



The mass of the removed disc $= \sigma(\pi R^2) = \pi\sigma R^2$

Let us consider the above situation to be a complete disc of radius $2R$ on which a disc of radius R of negative mass is superimposed. Let O be the origin. Then the above figure can be redrawn keeping in mind the concept of centre of mass as :

$$x_{c.m} = \frac{\left(6\pi(2R)^2\right)\times 0 + \left(-6\left(\pi R^2\right)\right)R}{4\pi\sigma R^2 - \pi\sigma R^2}$$

$$\therefore\ x_{c.m} = \frac{-\pi\sigma R^2\times R}{3\pi\sigma R^2}$$

$$\therefore\ x_{c.m} = -\frac{R}{3} = \alpha R \Rightarrow \alpha = \frac{1}{3}$$

18. (b) Acceleration of the body rolling down an inclined plane is given by.

$$a = \frac{g\sin\theta}{1+\frac{I}{MR^2}}$$

19. (d) We know Torque $\vec{\tau_c} = \frac{d\vec{L_c}}{dt}$

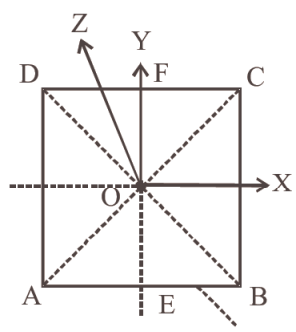
where $\vec{L_c}$ = Angular momentum about the center of mass of the body. Central forces act along the center of mass. Therefore torque about center of mass is zero.

$$\therefore \tau = \frac{dL}{dt} = 0 \qquad \Rightarrow \vec{L_c} = \text{constt.}$$

20. (d) By the theorem of perpendicular axes, $I = I_{EF} + I_{GH}$

Here, I is the moment of inertia of square lamina about an axis through O and perpendicular to its plane.

$\therefore\ I_{EF} = I_{GH}$ (By Symmetry of Figure)



$$\therefore\ I_{EF} = \frac{I}{2} \qquad \text{...(i)}$$

Again, by the same theorem $I = I_{AC} + I_{BD} = 2I_{AC}$ ($\therefore\ I_{AC} = I_{BD}$ by symmetry of the figure)

$$\therefore\ I_{AC} = \frac{I}{2} \qquad \text{...(ii)}$$

From (i) and (ii), we get, $I_{EF} = I_{AC}$.

21. (a) • The linear mass density $\lambda = k\left(\frac{x}{L}\right)^n$

$$Here \quad \frac{x}{L} \le 1$$

With increase in the value of n, the centre of mass shift towards the end $x = L$ This is satisfied by only option (a).

$$x_{CM} = \frac{\int_0^L x\,dm}{\int_0^L dm} = \frac{\int_0^L x(\lambda dx)}{\int_0^L \lambda\, dx} = \frac{\int_0^L k\left(\frac{x}{L}\right)^n .xdx}{\int_0^L k\left(\frac{x}{L}\right)^n dx}$$

$$= \frac{k\left[\frac{x^{n+2}}{(n+2)L^n}\right]_0^L}{\left[\frac{k\,x^{n+1}}{(n+1)L^n}\right]_0^L} = \frac{L(n+1)}{n+2}$$

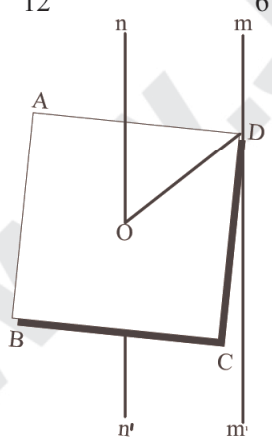
For $n = 0, x_{CM} = \frac{L}{2}$; $n = 1$,

$x_{CM} = \frac{2L}{3}$; $n = 2$, $x_{CM} = \frac{3L}{4}$;....

For $n \to \infty x_{cm} = L$

Moment of inertia of a square plate about an axis through its centre and perpendicular to its plane is.

22. (d) $I_{nn'} = \frac{1}{12}M(a^2 + a^2) = \frac{Ma^2}{6}$



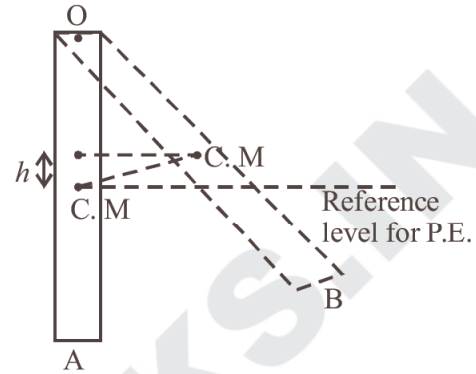
Also, $DO = \frac{DB}{2} = \frac{\sqrt{2}a}{2} = \frac{a}{\sqrt{2}}$

By parallel axes the orem, moment of inertia of plate about an axis through one of its corners.

$$I_{mm'} = I_{nn'} + M\left(\frac{a}{\sqrt{2}}\right)^2 = \frac{Ma^2}{6} + \frac{Ma^2}{2}$$

$$= \frac{Ma^2 + 3Ma^2}{6} = \frac{2}{3}Ma^2$$

23. (c)



The moment of inertia of the rod about O is $\frac{1}{3}m\ell^2$. The kinetic energy of the rod at position A = $\frac{1}{2}I\omega^2$ where I is the moment of inertia of the rod about O. When the rod is in position B, its angular velocity is zero. In this case, the energy of the rod is mgh where h is the maximum height to which the centre of mass (C.M) rises

Gain in potential energy = Loss in kinetic energy

$$\therefore\ mgh = \frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{1}{3}ml^2\right)\omega^2$$

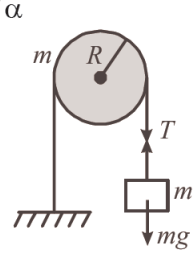
$$\Rightarrow\ h = \frac{\ell^2\omega^2}{6g}$$

24. (b) For translational motion,

$mg - T = ma$ .....(1)

For rotational motion,

T.R = $I\alpha$



$$\Rightarrow \text{T.R} = \frac{1}{2}mR^2\alpha$$

Also, acceleration, a = Rα

$$\therefore T = \frac{1}{2}mR\alpha = \frac{1}{2}ma$$

Substituting the value of T is equation (1)

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we get mg - $\frac{1}{2}ma = ma \Rightarrow a = \frac{2}{3}g$

25. (c) Angular momentum, L = Iω ⇒ $L = mr^2\omega$
As insect moves along a diameter, the effective mass and hence moment of inertia (I) first decreases then increases so from principle of conservation of angular momentum, angular speed ω first increases then decreases.

26. (a) Given,
Force, $F = (20t - 5t^2)$
Radius, $r = 2m$
Torque, $T = r f = I\alpha$
$\Rightarrow 2(20t - 5t^2) = 10\alpha$
$\therefore \alpha = 4t - t^2$

$$\Rightarrow \frac{d\omega}{dt} = 4t - t^2$$

$$\Rightarrow \int_0^{\omega} d\omega = \int_0^t \left(4t - t^2\right)dt$$

$$\Rightarrow \omega = 2t^2 - \frac{t^3}{3} \text{ (as } \omega = 0 \text{ at } t = 0, 6\text{s)}$$

$$\int_0^{\theta} d\theta = \int_0^6 \left(2t^2 - \frac{t^3}{3}\right)dt$$

$\Rightarrow \theta = 36$ rad
$\Rightarrow 2\pi n = 36$

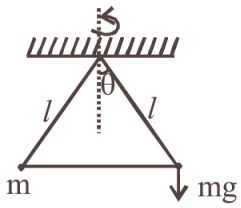
$$\Rightarrow n = \frac{36}{2\pi} < 6$$

27. (c)

From conservation of angular momentum about any fix point on the surface,
$mr^2\omega_0 = 2mr^2\omega$

$$\Rightarrow \omega = \omega_0/2 \Rightarrow v = \frac{\omega_0 r}{2} \quad [\because v = r\omega]$$

28. (c) Torque working on the bob of mass m is, $\tau = mg \times \ell \sin\theta$. (Direction parallel to plane of rotation of particle)

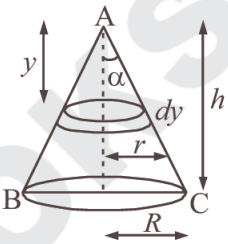


As τ is perpendicular to $\vec{L}$, direction of L changes but magnitude remains same.

29. (d) Let density of cone = ρ.

Centre of mass, $ycm = \frac{\int y dm}{\int dm}$

$$= \frac{\int_0^h y\pi r^2 d y\rho}{\frac{1}{3}\pi R^2 h\rho} = \frac{\int_0^h r^2 y dy}{\frac{1}{3}R^2 h} \quad ...(i)$$



For a cone, we know that

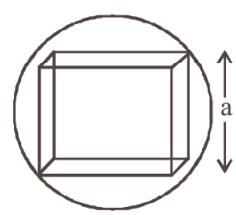
$$\frac{r}{R} = \frac{y}{n} \quad \therefore r = \frac{y}{n}R$$

$$ycm = \frac{\int_0^h 3y^3 dy}{h^3} = \frac{3\left[\frac{y^4}{4}\right]_0^h}{h^3} = \frac{3}{4}h$$

30. (a) Here $a = \frac{2}{\sqrt{3}}R$

Now, $\frac{M}{M'} = \frac{\frac{4}{3}\pi R^3}{a^3}$

$$= \frac{\frac{4}{3}\pi R^3}{\left(\frac{2}{\sqrt{3}}R\right)^3} = \frac{\sqrt{3}}{2}\pi.$$

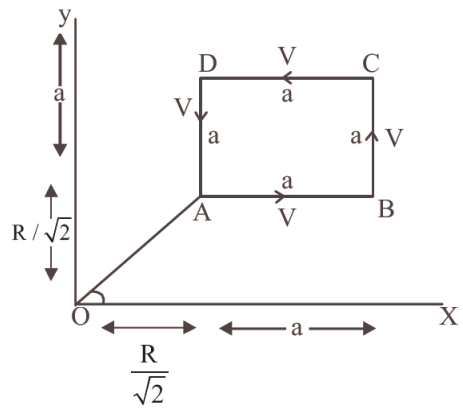


$$M' = \frac{2M}{\sqrt{3}\pi}$$

Moment of inertia of the cube about the given axis, $I = \frac{M'a^2}{6}$

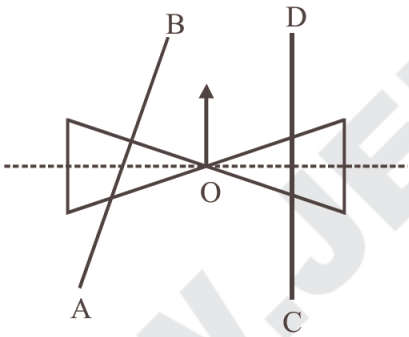
$$= \frac{\frac{2M}{\sqrt{3}\pi} \times \left(\frac{2}{\sqrt{3}}R\right)^2}{6} = \frac{4MR^2}{9\sqrt{3}\pi}$$

31. (a) We know that $|L| = mvr_{\perp}$



In none of the cases, the perpendicular distance $r_\perp$ is $\left(\frac{R}{\sqrt{2}}+a\right)$

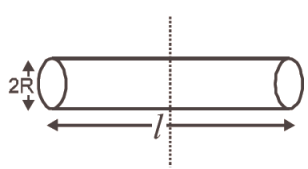
32. **(c)** As shown in the diagram, the normal reaction of AB on roller will shift towards O.
This will lead to tending of the system of cones to turn left.



33. **(c)** As we know, moment of inertia of a solid cylinder about an axis which is perpendicular bisector

$$I=\frac{mR^2}{4}+\frac{ml^2}{12}$$

$$I=\frac{m}{4}\left[R^2+\frac{l^2}{3}\right]$$



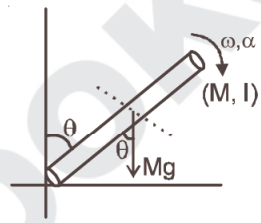
$$=\frac{m}{4}\left[\frac{V}{\pi l}+\frac{l^2}{3}\right] \Rightarrow \frac{dl}{dl}=\frac{m}{4}\left[\frac{-V}{\pi l^2}+\frac{2l}{3}\right]=0$$

$$\frac{V}{\pi l^2}=\frac{2l}{3} \quad \Rightarrow V=\frac{2\pi l^3}{3}$$

$$\pi R^2 l=\frac{2\pi l^3}{3} \Rightarrow \frac{l^2}{R^2}=\frac{3}{2} \text{ or, } \frac{l}{R}=\sqrt{\frac{3}{2}}$$

34. **(c)** Torque at angle θ

$$\tau = Mg\sin\theta\cdot\frac{l}{2}$$



Also $\tau = I\alpha$

$$\therefore \quad I\alpha = Mg\sin\theta\frac{l}{2}$$

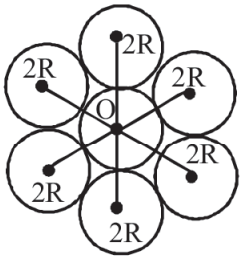
$$\frac{Ml^2}{3}\cdot\alpha = Mg\sin\theta\frac{l}{2} \quad \left[\because I_{rod}=\frac{Ml^2}{3}\right]$$

$$\Rightarrow \frac{l\alpha}{3}=g\frac{\sin\theta}{2} \qquad \therefore \quad \alpha=\frac{3g\sin\theta}{2l}$$

35. **(d)** Using parallel axes theorem, moment of inertia about '*O*'

$I_o = I_{cm} + md^2$

$$=\frac{7MR^2}{2}+6(M\times(2R)^2)=\frac{55MR^2}{2}$$



Again, moment of inertia about point *P*,
$I_p = I_o + md^2$

$$=\frac{55MR^2}{2}+7M(3R)^2=\frac{181}{2}MR^2$$

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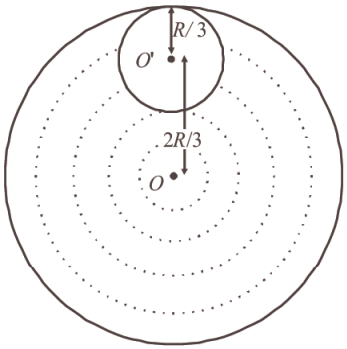
36. (a) Let σ be the mass per unit area.



The total mass of the disc

$= \sigma \times \pi R^2 = 9M$

The mass of the circular disc cut

$$= \sigma \times \pi \left(\frac{R}{3}\right)^2 = \sigma \times \frac{\pi R^2}{9} = M$$

Let us consider the above system as a complete disc of mass $9M$ and a negative mass M super imposed on it.

Moment of inertia (I_1) of the complete disc $= \frac{1}{2} 9MR^2$ about an axis passing through O and perpendicular to the plane of the disc.

M.I. of the cut out portion about an axis passing through O' and perpendicular to the plane of disc

$$= \frac{1}{2} \times M \times \left(\frac{R}{3}\right)^2$$

$\therefore$ *M.I.* (I_2) of the cut out portion about an axis passing through O and perpendicular to the plane of disc

$$= \left[\frac{1}{2} \times M \times \left(\frac{R}{3}\right)^2 + M \times \left(\frac{2R}{3}\right)^2\right]$$

[Using perpendicular axis theorem]

$\therefore$ The total *M.I.* of the system about an axis passing through O and perpendicular to the plane of the disc is

$I = I_1 + I_2$

$$= \frac{1}{2} 9MR^2 - \left[\frac{1}{2} \times M \times \left(\frac{R}{3}\right)^2 + M \times \left(\frac{2R}{3}\right)^2\right]$$

$$= \frac{9MR^2}{2} - \frac{9MR^2}{18} = \frac{(9-1)MR^2}{2} = 4MR^2$$

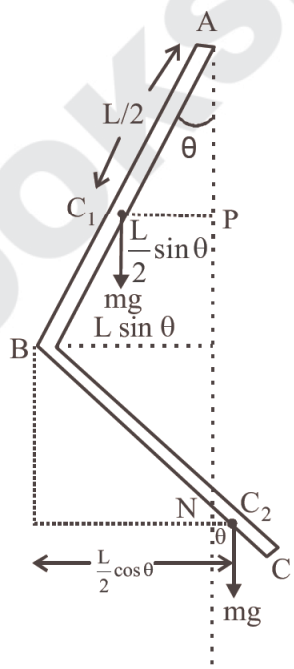
37. (d) Given that, the rod is of uniform mass density and AB = BC

Let mass of one rod is m.

Balancing torque about hinge point.

$mg\,(C_1P) = mg\,(C_2N)$

$$mg\left(\frac{L}{2}\sin\theta\right) = mg\left(\frac{L}{2}\cos\theta - L\sin\theta\right)$$



$$\Rightarrow \frac{3}{2} mgL\sin\theta = \frac{mgL}{2}\cos\theta \Rightarrow \frac{\sin\theta}{\cos\theta} = \frac{1}{3}$$

or, $\tan\theta = \frac{1}{3}$

38. (c) Distance of c.m from m/2

$$= \frac{\frac{m}{2} \times 0 + m \times \ell}{\frac{m}{2} + m} = \frac{2\ell}{3}$$

$$I_{cm} = \frac{m}{2}\left(\frac{2\ell}{3}\right)^2 + m\left(\frac{\ell}{3}\right)^2 = \frac{1}{3} m\ell^2$$

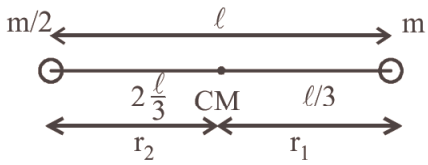
At the mean position

$$\frac{1}{2} I_{cm}\omega^2 = \frac{1}{2} k\theta_0^2$$

$$\therefore \omega^2 = \frac{k}{I_{cm}}\theta_0^2$$

$$\omega^2 = \frac{3k}{m\ell^2}\theta_0^2$$

As we know, $\omega = \sqrt{\frac{k}{I_{cm}}}$



Tension in the rod when it passes through the mean position,

$$= m\omega^2 \frac{\ell}{3} = m\left[\frac{3k}{m\ell^2}\theta_0^2\right]\frac{\ell}{3} = \frac{k\theta_0^2}{\ell}$$

39. (d) Work done by torque is responsible for change in kinetic energy.

$$\therefore \tau = \frac{dE}{d\theta} \quad \therefore I\alpha = 2K\theta \therefore \alpha = \frac{2k\theta}{I}$$

40. (c) $mgh = \frac{1}{2}mv_{cm}^2 + \frac{1}{2}I_{cm}\omega^2$

$$= \frac{1}{2}mv_{cm}^2 + \frac{1}{2}I_{cm}\left(\frac{v_{cm}}{R}\right)^2$$

$$= \frac{1}{2}\left(m + \frac{I_{cm}}{R^2}\right)v_{cm}^2 = \frac{1m}{2}\left[1 + \frac{K^2}{R^2}\right]$$

$$\therefore \eta \propto 1 + \frac{K^2}{R^2}$$

For ring : $h \propto 2$ ($\therefore$ K = R)

For solid cylisnder, $h \propto \frac{3}{2}$ $\left(\because K = \frac{R}{\sqrt{2}}\right)$

For solid sphere, $h \propto \frac{7}{5}$ $\left(\because K = \sqrt{\frac{2}{5}}R\right)$

Ratio of heights $2 : \frac{3}{2} : \frac{7}{5} \Rightarrow 20 : 15 : 14$

41. (a) When the bob covered a distance 'h'

Using $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

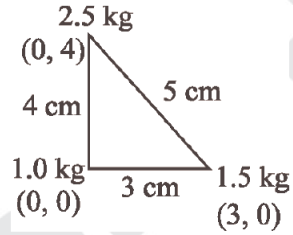
$$= \frac{1}{2}m(\omega r)^2 + \frac{1}{2} \times \frac{mr^2}{2} \times \omega^2$$

($\because v = \omega r$ no slipping)

$$\Rightarrow mgh = \frac{3}{4}m\omega^2 r^2$$

$$\Rightarrow \omega = \sqrt{\frac{4gh}{3r^2}} = \frac{1}{r}\sqrt{\frac{4gh}{3}}$$

42. (d)



$$X_{cm} = \frac{m_1x_1 + m_2x_2 + m_3x_3}{m_1 + m_2 + m_3}$$

$$X_{cm} = \frac{1 \times 0 + 1.5 \times 3 + 2.5 \times 0}{1 + 1.5 + 2.5} = \frac{1.5 \times 3}{5}$$

$$= 0.9cm$$

$$Y_{cm} = \frac{m_1y_1 + m_2y_2 + m_3y_3}{m_1 + m_2 + m_3}$$

$$Y_{cm} = \frac{1 \times 0 + 1.5 \times 0 + 2.5 \times 4}{1 + 1.5 + 2.5}$$

$$= \frac{2.5 \times 4}{5} = 2cm$$

Hence, centre of mass of system is at point (0.9, 2)

43. (c) Moment inertia of the rod passing through a point away from the centre of the rod $\frac{\ell}{4}$

$I = Ig + m\ell^2$

$$\Rightarrow I = \frac{MI^2}{12} + M \times \left(\frac{I^2}{16}\right) = \frac{7MI^2}{48}$$

Using $I = MK^2 = \frac{7MI^2}{48}$ (K = radius of gyration)

$$\Rightarrow K = \sqrt{\frac{7}{48}}I$$

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7 Gravitation

1. The kinetic energy needed to project a body of mass m from the earth surface (radius R) to infinity is **[2002]**
   (a) $mgR/2$ (b) $2mgR$
   (c) mgR (d) $mgR/4$.
2. If suddenly the gravitational force of attraction between Earth and a satellite revolving around it becomes zero, then the satellite will **[2002]**
   (a) continue to move in its orbit with same velocity
   (b) move tangentially to the original orbit in the same velocity
   (c) become stationary in its orbit
   (d) move towards the earth
3. Energy required to move a body of mass m from an orbit of radius $2R$ to $3R$ is **[2002]**
   (a) $GMm/12R^2$ (b) $GMm/3R^2$
   (c) $GMm/8R$ (d) $GMm/6R$.
4. The escape velocity of a body depends upon mass as **[2002]**
   (a) m^0 (b) m^1
   (c) m^2 (d) m^3
5. The time period of a satellite of earth is 5 hours. If the separation between the earth and the satellite is increased to 4 times the previous value, the new time period will become **[2003]**
   (a) 10 hours (b) 80 hours
   (c) 40 hours (d) 20 hours
6. Two spherical bodies of mass M and $5M$ & radii R & $2R$ respectively are released in free space with initial separation between their centres equal to 12 R. If they attract each other due to gravitational force only, then the distance covered by the smaller body just before collision is **[2003]**
   (a) $2.5R$ (b) $4.5R$
   (c) $7.5R$ (d) $1.5R$
7. The escape velocity for a body projected vertically upwards from the surface of earth is 11 km/s. If the body is projected at an angle of 45°with the vertical, the escape velocity will be **[2003]**
   (a) $11\sqrt{2}$ km/s (b) 22 km/s
   (c) 11 km/s (d) $\frac{11}{\sqrt{2}}$ km/s
8. A satellite of mass m revolves around the earth of radius R at a height x from its surface. If g is the acceleration due to gravity on the surface of the earth, the orbital speed of the satellite is **[2004]**
   (a) $\frac{gR^2}{R+x}$ (b) $\frac{gR}{R-x}$
   (c) gx (d) $\left(\frac{gR^2}{R+x}\right)^{1/2}$
9. The time period of an earth satellite in circular orbit is independent of **[2004]**
   (a) both the mass and radius of the orbit
   (b) radius of its orbit
   (c) the mass of the satellite
   (d) neither the mass of the satellite nor the radius of its orbit.
10. If 'g' is the acceleration due to gravity on the earth's surface, the gain in the potential energy of an object of mass 'm' raised from the surface of the earth to a height equal to the radius 'R' of the earth is **[2004]**
    (a) $\frac{1}{4}mgR$ (b) $\frac{1}{2}mgR$
    (c) $2mgR$ (d) mgR
11. Suppose the gravitational force varies inversely as the nth power of distance. Then the time period of a planet in circular orbit of radius 'R' around the sun will be proportional to **[2004]**
    (a) R^n (b) $R^{\left(\frac{n-1}{2}\right)}$
    (c) $R^{\left(\frac{n+1}{2}\right)}$ (d) $R^{\left(\frac{n-2}{2}\right)}$

12. The change in the value of 'g' at a height 'h' above the surface of the earth is the same as at a depth 'd' below the surface of earth. When both 'd' and 'h' are much smaller than the radius of earth, then which one of the following is correct? **[2005]**

(a) $d = \frac{3h}{2}$ (b) $d = \frac{h}{2}$

(c) $d = h$ (d) $d = 2h$

13. A particle of mass 10 g is kept on the surface of a uniform sphere of mass 100 kg and radius 10 cm. Find the work to be done against the gravitational force between them to take the particle far away from the sphere **[2005]**

(you may take $G = 6.67 \times 10^{-11}\ \text{Nm}^2/\text{kg}^2$)

(a) 3.33×10^{-10} J (b) 13.34×10^{-10} J

(c) 6.67×10^{-10} J (d) 6.67×10^{-9} J

14. Average density of the earth **[2005]**

(a) is a complex function of g

(b) does not depend on g

(c) is inversely proportional to g

(d) is directly proportional to g

15. A planet in a distant solar system is 10 times more massive than the earth and its radius is 10 times smaller. Given that the escape velocity from the earth is 11 km s^{-1}, the escape velocity from the surface of the planet would be **[2008]**

(a) 1.1 km s^{-1} (b) 11 km s^{-1}

(c) 110 km s^{-1} (d) 0.11 km s^{-1}

16. This question contains Statement-1 and Statement-2. Of the four choices given after the statements, choose the one that best describes the two statements. **[2008]**

Statement-1 : For a mass M kept at the centre of a cube of side 'a', the flux of gravitational field passing through its sides $4\pi GM$. and

Statement-2: If the direction of a field due to a point source is radial and its dependence on the distance 'r' from the source is given as $\frac{1}{r^2}$, its flux through a closed surface depends only on the strength of the source enclosed by the surface and not on the size or shape of the surface.

(a) Statement -1 is false, Statement-2 is true

(b) Statement -1 is true, Statement-2 is true; Statement -2 is a correct explanation for Statement-1

(c) Statement -1 is true, Statement-2 is true; Statement -2 is not a correct explanation for Statement-1

(d) Statement -1 is true, Statement-2 is false

17. The height at which the acceleration due to gravity becomes $\frac{g}{9}$ (where g = the acceleration due to gravity on the surface of the earth) in terms of R, the radius of the earth, is **[2009]**

(a) $\frac{R}{\sqrt{2}}$ (b) $R/2$

(c) $\sqrt{2}R$ (d) $2R$

18. Two bodies of masses m and $4m$ are placed at a distance r. The gravitational potential at a point on the line joining them where the gravitational field is zero is: **[2011]**

(a) $-\frac{4Gm}{r}$ (b) $-\frac{6Gm}{r}$

(c) $-\frac{9Gm}{r}$ (d) zero

19. Two particles of equal mass 'm' go around a circle of radius R under the action of their mutual gravitational attraction. The speed of each particle with respect to their centre of mass is **[2011 RS]**

(a) $\sqrt{\frac{Gm}{4R}}$ (b) $\sqrt{\frac{Gm}{3R}}$

(c) $\sqrt{\frac{Gm}{2R}}$ (d) $\sqrt{\frac{Gm}{R}}$

20. The mass of a spaceship is 1000 kg. It is to be launched from the earth's surface out into free space. The value of g and R (radius of earth) are 10 m/s^2 and 6400 km respectively. The required energy for this work will be **[2012]**

(a) 6.4×10^{11} Joules (b) 6.4×10^{8} Joules

(c) 6.4×10^{9} Joules (d) 6.4×10^{10} Joules

21. What is the minimum energy required to launch a satellite of mass m from the surface of a planet of mass M and radius R in a circular orbit at an altitude of 2R? **[2013]**

(a) $\frac{5GmM}{6R}$ (b) $\frac{2GmM}{3R}$

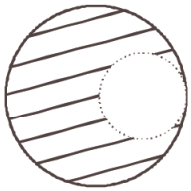
(c) $\frac{GmM}{2R}$ (d) $\frac{GmM}{2R}$

22. Four particles, each of mass M and equidistant from each other, move along a circle of radius R under the action of their mutual gravitational attraction. The speed of each particle is: **[2014]**

(a) $\sqrt{\frac{GM}{R}}$ (b) $\sqrt{2\sqrt{2}\frac{GM}{R}}$

(c) $\sqrt{\frac{GM}{R}\left(1+2\sqrt{2}\right)}$ (d) $\frac{1}{2}\sqrt{\frac{GM}{R}\left(1+2\sqrt{2}\right)}$

23. From a solid sphere of mass M and radius R, a spherical portion of radius R/2 is removed, as shown in the figure. Taking gravitational potential V = 0 at r = ∞, the potential at the centre of the cavity thus formed is : **[2015]**
(*G = gravitational constant*)



(a) $\frac{-2GM}{3R}$ (b) $\frac{-2GM}{R}$

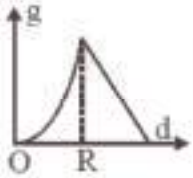
(c) $\frac{-GM}{2R}$ (d) $\frac{-GM}{R}$

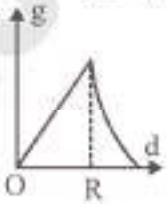
24. A satellite is revolving in a circular orbit at a height 'h' from the earth's surface (radius of earth R; h << R). The minimum increase in its orbital velocity required, so that the satellite could escape from the earth's gravitational field, is close to : (Neglect the effect of atmosphere.) **[2016]**

(a) $\sqrt{gR/2}$ (b) $\sqrt{gR}\left(\sqrt{2}-1\right)$

(c) $\sqrt{2gR}$ (d) $\sqrt{gR}$

25. The variation of acceleration due to gravity g with distance *d* from centre of the earth is best represented by (R = Earth's radius): **[2017]**

(a)


(b)


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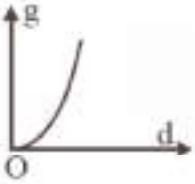
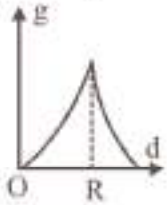


(d)


26. A particle is moving with a uniform speed in a circular orbit of radius R in a central force inversely proportional to the nth power of R. If the period of rotation of the particle is T, then: **[2018]**

(a) $T \propto R^{3/2}$ for any n. (b) $T \propto R^{n/2+1}$

(c) $T \propto R^{(n+1)/2}$ (d) $T \propto R^{n/2}$

27. If the angular momentum of a planet of mass m, moving around the Sun in a circular orbit is L, about the center of the Sun, its areal velocity is: **[2019]**

(a) $\frac{L}{m}$ (b) $\frac{4L}{m}$ (c) $\frac{L}{2m}$ (d) $\frac{2L}{m}$

28. A solid sphere of mass 'M' and radius '*a*' is surrounded by a uniform concentric spherical shell of thickness 2*a* and mass 2M. The gravitational field at distance '3*a*' from the centre will be: **[2019]**

(a) $\frac{2GM}{9a^2}$ (b) $\frac{GM}{9a^2}$

(c) $\frac{GM}{3a^2}$ (d) $\frac{2GM}{3a^2}$

29. A satellite of mass *m* is launched vertically upwards with an initial speed *u* from the surface of the earth. After it reaches height *R* (*R* = radius of the earth), it ejects a rocket of mass so that subsequently the satellite moves in a circular orbit. The kinetic energy of the rocket is (*G* is the gravitational constant; *M* is the mass of the earth): **[2020]**

(a) $\frac{m}{20}\left(u^2+\frac{113}{200}\frac{GM}{R}\right)$

(b) $5m\left(u^2-\frac{119}{200}\frac{GM}{R}\right)$

(c) $\frac{3m}{8}\left(u+\sqrt{\frac{5GM}{6R}}\right)^2$

(d) $\frac{m}{20}\left(u-\sqrt{\frac{2GM}{3R}}\right)^2$

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(c)	(b)	(d)	(a)	(c)	(c)	(c)	(d)	(c)	(b)	(c)	(d)	(c)	(d)	(c)
16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	
(b)	(d)	(c)	(a)	(d)	(a)	(d)	(d)	(b)	(b)	(c)	(c)	(c)	(b)	

Solutions

1. **(c)** $K.E = \frac{1}{2} m v_e^2$

Here v_e = escape velocity is independent of mass of the body

Escape velocity, $v_e = \sqrt{2gR}$

Substituting value of v_e in above equation we get

$$K.E = \frac{1}{2} m \times 2gR = mgR$$

2. **(b)** Due to inertia of motion it will move tangentially to the original orbit with the same velocity.

3. **(d)** Gravitational potential energy of mass m in an orbit of radius R

$$u = -\frac{GMm}{R}$$

Energy required = potential energy at 3R – potential energy a 2R

$$= \frac{-GMm}{3R} - \left(\frac{-GMm}{2R}\right)$$

$$= \frac{-GMm}{3R} + \frac{GMm}{2R}$$

$$= \frac{-2GMm + 3GMm}{6R} = \frac{GMm}{6R}$$

4. **(a)** Escape velocity, $v_e = \sqrt{2gR} = \sqrt{\frac{2GM}{R}}$

$\Rightarrow v_e \propto m^0$

Where M, R are the mass and radius of the planet respectively. Clearly, escape velocity is independent of mass of the body

5. **(c)** According to Kepler's law of periods $T^2 \propto R^3$

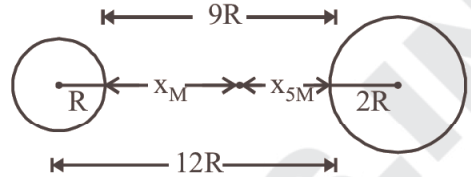
$$\therefore \left(\frac{T_2}{T_1}\right)^2 = \left(\frac{R_2}{R_1}\right)^3$$

$$\Rightarrow T_2 = T_1\left(\frac{R_2}{R_1}\right)^{3/2} = 5 \times \left[\frac{4R}{R}\right]^{3/2}$$

$= 5 \times 2^3 = 40$ hours

6. **(c)** We know that

Force = mass × acceleration.



The gravitational force acting on both the masses is the same.

$F_1 = F_2$

$ma_1 = ma_2$

$$\Rightarrow \frac{9M}{95M} = \frac{5M}{M} = 5$$

$$\Rightarrow \frac{9M}{95M} = \frac{1}{5}$$

Let t be the time taken for the two masses to collide and x_{5M}, x_M be the distance travelled by the mass $5M$ and M respectively.

For mass 5*M*

$u = 0$,

$$S = ut + \frac{1}{2}at^2$$

$$\therefore \; x_{5M} = \frac{1}{2}a_{5M}t^2 \quad \text{....(ii)}$$

For mass *M*

$u = 0, s = x_M, t = t, \; a = a_M$

$$\therefore \; s = ut + \frac{1}{2}at^2$$

$$\Rightarrow x_M = \frac{1}{2}a_M t^2 \quad \text{...(iii)}$$

Dividing (ii) by (iii)

$$\frac{x_{5M}}{x_M} = \frac{\frac{1}{2}a_{5M}t^2}{\frac{1}{2}a_M t^2} = \frac{a_{5M}}{a_M} = \frac{1}{5} \quad \text{[From (i)]}$$

$$\therefore \; 5x_{5M} = x_M \quad \text{....(iv)}$$

From the figure it is clear that

$$x_{5M} + x_M = 9R \quad \text{....(v)}$$

Where O is the point where the two spheres collide.

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From (iv) and (v)

$$\frac{x_M}{5} + x_M = 9R$$

$$\therefore \quad 6x_M = 45R$$

$$\therefore \quad x_M = \frac{45}{6}R = 7.5R$$

7. **(c)** $v_e = \sqrt{2gR}$

Clearly escape velocity does not depend on the angle at which the body is projected.

8. **(d)** Gravitational force provides the necessary centripetal force.

$\therefore$ Centripetal force on a satellite = Gravitational force

$$\therefore \quad \frac{mv^2}{(R+x)} = \frac{GmM}{(R+x)^2} \text{ also } g = \frac{GM}{R^2}$$

$$\therefore \frac{mv^2}{(R+x)} = m\left(\frac{GM}{R^2}\right)\frac{R^2}{(R+x)^2}\frac{n!}{r!(n-r)!}$$

$$\therefore \frac{mv^2}{(R+x)} = mg\frac{R^2}{(R+x)^2}$$

$$\therefore v^2 = \frac{gR^2}{R+x} \Rightarrow v = \left(\frac{gR^2}{R+x}\right)^{1/2}$$

9. **(c)** Time period of satellite is given by

$$T = 2\pi\sqrt{\frac{(R+h)^3}{GM}}$$

Where $R + h$ = radius of orbit of satellite

M = mass of earth.

Time period is independent of mass of satellite.

10. **(b)** On earth's surface potential energy,

$$U = \frac{GmM}{R}$$

At a height R from the earth's surface, $P.E.$ of system $= -\frac{GmM}{2R}$

$$\therefore \Delta U = \frac{-GmM}{2R} + \frac{GmM}{R};$$

$$\Rightarrow \Delta U = \frac{GmM}{2R}$$

Now $\frac{GM}{R^2} = g$; $\therefore \frac{GM}{R} = gR$

$$\therefore \Delta U = \frac{1}{2}mgR$$

11. **(c)** Gravitational force, $F = KR^{-n}$

This force provides the centripetal force $MR\omega^2$ to the planet at height h above earth's surface.

$\therefore \quad F = KR^{-n} = MR\omega^2$

$\Rightarrow \quad \omega^2 = KR^{-(n+1)}$

$$\Rightarrow \quad \omega = KR^{\frac{-(n+1)}{2}}$$

$$\frac{2\pi}{T} \propto R^{\frac{-(n+1)}{2}}$$

$$\therefore T \propto R^{\frac{+(n+1)}{2}}$$

12. **(d)** Value of g with altitude is,

$$g_h = g\left[1 - \frac{2h}{R}\right];$$

Value of g at depth d below earth's surface,

$$g_d = g\left[1 - \frac{d}{R}\right]$$

Equating g_h and g_d, we get $d = 2h$

13. **(c)** Initial P.E. $U_i = -\frac{GMm}{R}$

When the particle is far away from the sphere, the P.E. of the system is zero.

$\therefore \quad U_f = 0$

$$W = \Delta U = U_f - U_i = 0 - \left[\frac{-GMm}{R}\right]$$

$$W = \frac{6.67 \times 10^{-11} \times 100}{0.1} \times \frac{10}{1000}$$

$$= 6.67 \times 10^{-10} \text{ J}$$

14. **(d)** Value of g on earth's surface,

$$g = \frac{GM}{R^2} = \frac{G\rho \times V}{R^2}$$

$$\Rightarrow \quad g = \frac{G \times \rho \times \frac{4}{3}\pi R^3}{R^2}$$

$g = \frac{4}{3}\rho\pi G.R$ where $\rho \rightarrow$ average density

$$\rho = \left(\frac{3g}{4\pi GR}\right)$$

$\Rightarrow \rho$ is directly proportional to g.

15. **(c)** Escape velocity on earth,

$$v_e = \sqrt{\frac{2GM_e}{R_e}} = 11 \text{ km } s^{-1}$$

$$\therefore \quad \frac{(v_e)_p}{(v_e)_e} = \frac{\sqrt{\frac{2GM_p}{R_p}}}{\sqrt{\frac{2GM_e}{R_e}}} = \sqrt{\frac{M_p}{M_e} \times \frac{R_e}{R_p}}$$

$$= \sqrt{\frac{10M_e}{M_e} \times \frac{R_e}{R_e/10}} = 10$$

$$\therefore \ (v_e)_p = 10 \times (v_e)_e = 10 \times 11 = 110 \ km/s$$

16. **(b)** Gravitational field, $E = -\frac{GM}{r^2}$

Flux, $\phi = \int \vec{E_g} \cdot \vec{dS} = | E \cdot 4\pi r^2 | = -4\pi GM$

where, M = mass enclosed in the closed surface

This relationship is valid when $| \vec{E}_g | \mu \frac{1}{r^2}$.

17. **(d)** On earth's surface $g = \frac{GM}{R^2}$

At height above earth's surface

$$g_h = \frac{GM}{(R+h)^2}$$

$$\therefore \ \frac{g_n}{g} = \frac{R^2}{(R+h)^2}$$

$$\Rightarrow \frac{g/9}{g} = \left[\frac{R}{R+h}\right]^2$$

$$\Rightarrow \frac{R}{R+h} = \frac{1}{3}$$

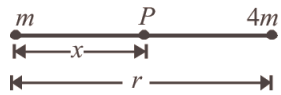
$$\therefore \quad h = 2R$$

18. **(c)** Let P be the point where gravitational field is zero.

$$\therefore \ \frac{Gm}{x^2} = \frac{4Gm}{(r-x)^2}$$

$$\Rightarrow \frac{1}{x} = \frac{2}{r-x} \quad \Rightarrow r - x = 2x$$

$$\Rightarrow \ x = \frac{r}{3}$$

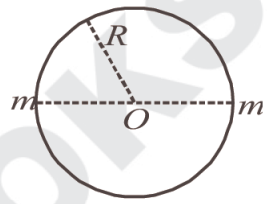


Gravitational potential at P,

$$V = -\frac{Gm}{\frac{r}{3}} - \frac{4Gm}{\frac{2r}{3}} = -\frac{9Gm}{r}$$

19. **(a)** As two masses revolve about the common centre of mass O.

$\therefore$ Mutual gravitational attraction = centripetal force



$$\frac{Gm^2}{(2R)^2} = m\omega^2 R$$

$$\Rightarrow \ \frac{Gm}{4R^3} = \omega^2$$

$$\Rightarrow \ \omega = \sqrt{\frac{Gm}{4R^3}}$$

If the velocity of the two particles with respect to the centre of gravity is v then $v = \omega R$

$$v = \sqrt{\frac{Gm}{4R^3}} \times R = \sqrt{\frac{Gm}{4R}}$$

20. **(d)** The work done to launch the spaceship

$$W = -\int_R^\infty \vec{F} \cdot \vec{dr} = -\int_R^\infty \frac{GMm}{r^2} dr$$

$$W = +\frac{GMm}{R} \qquad \ldots \text{(i)}$$

The force of attraction of the earth on the spaceship, when it was on the earth's surface

$$F = \frac{GMm}{R^2}$$

$$\Rightarrow \ mg = \frac{GMm}{R^2} \Rightarrow g = \frac{GM}{R^2} \qquad \ldots \text{(ii)}$$

Substituting the value of g in (i) we get

$$W = \frac{gR^2 m}{R}$$

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$\Rightarrow \; W = mgR$

$\Rightarrow W = 1000 \times 10 \times 6400 \times 10^3$

$= 6.4 \times 10^{10}$ Joule

21. **(a)** As we know,

Gravitational potential energy $= \dfrac{-GMm}{r}$

and orbital velocity, $v_0 = \sqrt{GM/R+h}$

$$E_f = \frac{1}{2}mv_0^2 - \frac{GMm}{3R} = \frac{1}{2}m\frac{GM}{3R} - \frac{GMm}{3R}$$

$$= \frac{GMm}{3R}\left(\frac{1}{2}-1\right) = \frac{-GMm}{6R}$$

$$E_i = \frac{-GMm}{R} + K$$

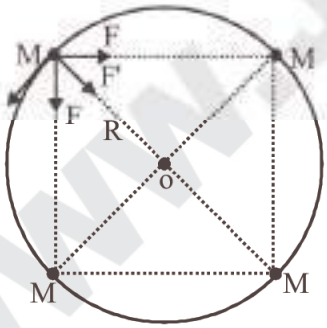
$E_i = E_f$

Therefore minimum required energy,

$$K = \frac{5GMm}{6R}$$

22. **(d)** $2F\cos 45° + F' = \dfrac{Mv^2}{R}$ (From figure)

Where $F = \dfrac{GM^2}{(\sqrt{2}R)^2}$ and $F' = \dfrac{GM^2}{4R^2}$



$$\Rightarrow \quad \frac{2\times GM^2}{\sqrt{2}(R\sqrt{2})^2} + \frac{GM^2}{4R^2} = \frac{Mv^2}{R}$$

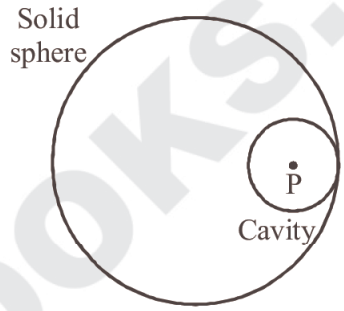
$$\Rightarrow \quad \frac{GM^2}{R}\left[\frac{1}{4}+\frac{1}{\sqrt{2}}\right] = Mv^2$$

$$\therefore \; v = \sqrt{\frac{GM}{R}\left(\frac{\sqrt{2}+4}{4\sqrt{2}}\right)} = \frac{1}{2}\sqrt{\frac{GM}{R}(1+2\sqrt{2})}$$

23. **(d)** Due to complete solid sphere, potential at point P

$$V_{sphere} = \frac{-GM}{2R^3}\left[3R^2 - \left(\frac{R}{2}\right)^2\right]$$

$$= \frac{-GM}{2R^3}\left(\frac{11R^2}{4}\right) = -11\frac{GM}{8R}$$



Due to cavity part potential at point P

$$V_{cavity} = -\frac{3}{2}\frac{\frac{GM}{8}}{\frac{R}{2}} = -\frac{3GM}{8R}$$

So potential at the centre of cavity

$= V_{sphere} - V_{cavity}$

$$= -\frac{11GM}{8R} - \left(-\frac{3}{8}\frac{GM}{R}\right) = \frac{-GM}{R}$$

24. **(b)** For h << R, the orbital velocity is $\sqrt{gR}$

Escape velocity $= \sqrt{2gR}$

$\therefore$ The minimum increase in its orbital velocity

$= \sqrt{2gR} - \sqrt{gR} = \sqrt{gR}\,(\sqrt{2}-1)$

25. **(b)** Variation of acceleration due to gravity, g with distance 'd' from centre of the earth

If $d < R, g = \dfrac{Gm}{R^2}\cdot d$ *i.e.*, $g \propto d$ (straight line)

If $d = R, g_s = \dfrac{Gm}{R^2}$

If $d > R, g = \dfrac{Gm}{d^2}$ *i.e.*, $g \propto \dfrac{1}{d^2}$

26. (c) $m\omega^2 R = \text{Force} \propto \frac{1}{R^n}$

$\left(\text{Force} = \frac{mv^2}{R}\right)$

$\Rightarrow \omega^2 \propto \frac{1}{R^{n+1}} \quad \Rightarrow \omega \propto \frac{1}{R^{\frac{n+1}{2}}}$

Time period $T = \frac{2\pi}{\omega}$

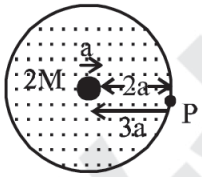
Time period, $T \propto R^{\frac{n+1}{2}}$

27. (c) Areal velocity $= \frac{\pi R^2}{T} = \frac{\pi R^2}{(2\pi R/v)} = \frac{vR}{2}$

$\therefore \quad \frac{dA}{dt} = \frac{R}{2} \times \frac{L}{mR} \quad [\because L = mvR]$

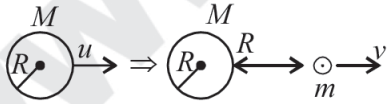
$\therefore \quad \frac{dA}{dt} = \frac{1}{2}\frac{L}{m}$

28. (c) $E_P = \frac{GM}{(3a)^2} + \frac{G(2M)}{(3a)^2} = \frac{GM}{3a^2}$



For a part on the surface of a spherical uniform charge distribution the whole mass acts as a point mass kept at the centre.

29. (b)



$\frac{1}{2}mu^2 + \frac{-GMm}{R} = \frac{1}{2}mv^2 + \frac{-GMm}{2R}$

$\Rightarrow \frac{1}{2}m(v^2 - u^2) = \frac{-GMm}{2R}$

$\Rightarrow V = \sqrt{V = u^2 - \frac{GM}{R}}$ ...(i)

$v_0 = \sqrt{\frac{GM}{2R}} \quad \therefore v_{rad} = \frac{m \times v}{\left(\frac{m}{10}\right)} = 10\,v$

Ejecting a rocket of mass $\frac{m}{10}$

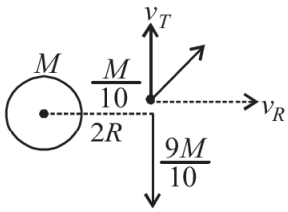
$\therefore \frac{9m}{10} \times \sqrt{\frac{GM}{2R}} = \frac{m}{10} \times v_\tau \Rightarrow V_\tau^2 = 81\frac{GM}{2R}$

Kinetic energy of rocket,

$KE_{rocket} = \frac{1}{2}\frac{M}{10}\left(V_T^2 + V_r^2\right)$

$= \frac{1}{2} \times \frac{m}{10} \times \left((u^2 - \frac{GM}{R})100 + 81\frac{GM}{R}\right)$

$= \frac{m}{20} \times 100\left(u^2 - \frac{GM}{R} + \frac{81}{200}\frac{GM}{R}\right)$



$= 5m\left(u^2 - \frac{119}{200}\frac{GM}{R}\right)$

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8 Mechanical Properties of Solids

1. A spring of force constant 800 N/m has an extension of 5 cm. The work done in extending it from 5 cm to 15 cm is **[2002]**
(a) 16 J (b) 8 J (c) 32 J (d) 24 J

2. A wire fixed at the upper end stretches by length ℓ by applying a force F. The work done in stretching is **[2004]**
(a) $2F\ell$ (b) $F\ell$ (c) $\frac{F}{2\ell}$ (d) $\frac{F\ell}{2}$

3. If 'S' is stress and 'Y' is young's modulus of material of a wire, the energy stored in the wire per unit volume is **[2005]**
(a) $\frac{S^2}{2Y}$ (b) $2S^2Y$ (c) $\frac{S}{2Y}$ (d) $\frac{2Y}{S^2}$

4. A wire elongates by l mm when a load W is hanged from it. If the wire goes over a pulley and two weights W each are hung at the two ends, the elongation of the wire will be (in mm) **[2006]**
(a) l (b) $2l$ (c) zero (d) $l/2$

5. Two wires are made of the same material and have the same volume. However wire 1 has cross-sectional area A and wire 2 has cross-sectional area $3A$. If the length of wire 1 increases by Δx on applying force F, how much force is needed to stretch wire 2 by the same amount? **[2009]**
(a) $4F$ (b) $6F$ (c) $9F$ (d) F

6. The pressure that has to be applied to the ends of a steel wire of length 10 cm to keep its length constant when its temperature is raised by 100ºC is:
(For steel Young's modulus is 2×10^{11} Nm^{-2} and coefficient of thermal expansion is 1.1×10^{-5}K^{-1}) **[2014]**
(a) 2.2×10^8 Pa (b) 2.2×10^9 Pa
(c) 2.2×10^7 Pa (d) 2.2×10^6 Pa

7. A solid sphere of radius r made of a soft material of bulk modulus K is surrounded by a liquid in a cylindrical container. A massless piston of area a floats on the surface of the liquid, covering entire cross-section of cylindrical container. When a mass m is placed on the surface of the piston to compress the liquid, the fractional decrement in the radius of the sphere $\left(\frac{dr}{r}\right)$, is : **[2018]**
(a) $\frac{Ka}{mg}$ (b) $\frac{Ka}{3mg}$ (c) $\frac{mg}{3Ka}$ (d) $\frac{mg}{Ka}$

Answer Key

1	2	3	4	5	6	7								
(b)	(d)	(a)	(a)	(c)	(a)	(c)								

Solutions

1. **(b)** Given, Force constant, $k = 800$ N/m
Initial extension, $x_1 = 5$cm
Final extension, $x_2 = 15$ cm
The work done is stored as elastic potential energy which is given by

$$W = \frac{1}{2} \times R\left(x_2^2 - x_1^2\right)$$

$$= \frac{800}{2}\left[(0.15)^2 - (0.05)^2\right]$$

$$= 400\,[(0.15 + 0.05)(0.15 - 0.05)]$$

$$= 400 \times 0.2 \times 0.1 = 8\text{ J}$$

2. **(d)** Let A and L be the area and length of the wire.

Work done by constant force in displacing the wire by a distance ℓ.
= change in potential energy

$$= \frac{1}{2} \times \text{stress} \times \text{strain} \times \text{volume}$$

$$= \frac{1}{2} \times \frac{F}{A} \times \frac{\ell}{L} \times A \times L = \frac{F\ell}{2}$$

3. **(a)** Energy stored in the wire per unit volume,

$$E = \frac{1}{2} \times \text{stress} \times \text{strain} \quad ...(i)$$

We know that,

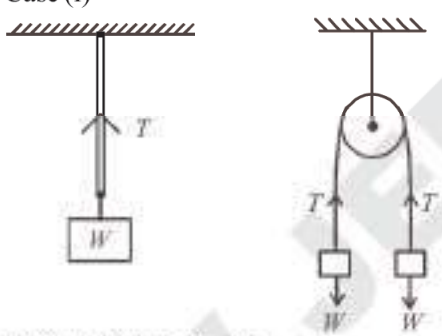
$$Y = \frac{\text{stress}}{\text{strain}}$$

$$\Rightarrow \text{strain} = \frac{\text{stress}}{Y}$$

On substituting the expression of strain in equation (i) we get

$$E = \frac{1}{2} \times \text{stress} \times \frac{\text{stress}}{Y} = \frac{1}{2} \cdot \frac{S^2}{Y}$$

4. **(a)** Case (i)



At equilibrium, $T = W$

Young's modules, $Y = \dfrac{W/A}{\ell/L}$ .....(1)

Elongation, $\ell = \dfrac{W}{A} \times \dfrac{L}{Y}$

Case (ii) At equilibrium $T = W$

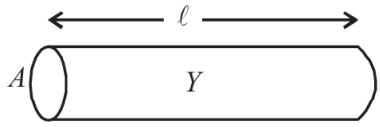
$\therefore$ Young's moduls, $Y = \dfrac{W/A}{\dfrac{\ell/2}{L/2}}$

$$\Rightarrow \quad Y = \frac{W/A}{\ell/L}$$

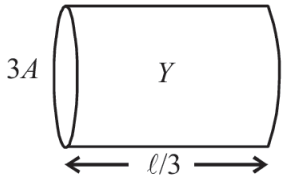
$$\Rightarrow \quad \ell = \frac{W}{A} \times \frac{L}{Y}$$

$\Rightarrow$ Elongation is the same.

5. **(c)**



Wire (1)



Wire (2)

For wire 1
Length, $L_1 = 1$
Area, $A_1 = A$
For wire 2
Length, $L_2 = \dfrac{\ell}{3}$
Area, $A_2 = 3A$
As the wires are made of same material, so they will have same young's modulus.
For wire 1,

$$Y = \frac{F/A}{\Delta x/\ell} \quad ...(i)$$

For wire 2 ,

$$Y = \frac{F'/3A}{\Delta x/(\ell/3)} \quad ...(ii)$$

From (i) and (ii) we get,

$$\frac{F}{A} \times \frac{\ell}{\Delta x} = \frac{F'}{3A} \times \frac{\ell}{3\Delta x} \Rightarrow F' = 9F$$

6. **(a)** Young's modulus $Y = \dfrac{\text{stress}}{\text{strain}}$

stress = Y × strain
Stress in steel wire = Applied pressure
Pressure = stress = Y × strain

$$\text{Strain} = \frac{\Delta L}{L} = \alpha \Delta T$$

(As length is constant)

$= 2 \times 10^{11} \times 1.1 \times 10^{-5} \times 100 = 2.2 \times 10^8$ Pa

7. **(c)** Bulk modulus, $K = \dfrac{\text{volumetric stress}}{\text{volumetric strain}}$

$$K = \frac{mg}{a\left(\dfrac{dV}{V}\right)}$$

$$\Rightarrow \quad \frac{dV}{V} = \frac{mg}{Ka} \quad ....(i)$$

volume of sphere, $V = \dfrac{4}{3}\pi R^3$

Fractional change in volume $\dfrac{dV}{V} = \dfrac{3dr}{r}$ ...(ii)

Using eq. (i) & (ii) $\dfrac{3dr}{r} = \dfrac{mg}{Ka}$

$\therefore \dfrac{dr}{r} = \dfrac{mg}{3Ka}$

(fractional decrement in radius)

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9 Mechanical Properties of Fluids

1. A cylinder of height 20 m is completely filled with water. The velocity of efflux of water (in ms^{-1}) through a small hole on the side wall of the cylinder near its bottom is **[2002]**
   (a) 10 (b) 20
   (c) 25.5 (d) 5

2. Spherical balls of radius 'R' are falling in a viscous fluid of viscosity 'η' with a velocity 'v'. The retarding viscous force acting on the spherical ball is **[2004]**
   (a) inversely proportional to both radius 'R' and velocity 'v'
   (b) directly proportional to both radius 'R' and velocity 'v'
   (c) directly proportional to 'R' but inversely proportional to 'v'
   (d) inversely proportional to 'R' but directly proportional to velocity 'v'

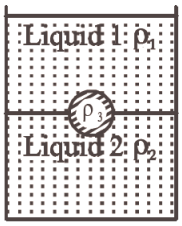
3. If two soap bubbles of different radii are connected by a tube **[2004]**
   (a) air flows from the smaller bubble to the bigger
   (b) air flows from bigger bubble to the smaller bubble till the sizes are interchanged
   (c) air flows from the bigger bubble to the smaller bubble till the sizes become equal
   (d) there is no flow of air.

4. A 20 cm long capillary tube is dipped in water. The water rises up to 8 cm. If the entire arrangement is put in a freely falling elevator the length of water column in the capillary tube will be **[2005]**
   (a) 10 cm (b) 8 cm
   (c) 20 cm (d) 4 cm

5. If the terminal speed of a sphere of gold (density = 19.5 kg/m^3) is 0.2 m/s in a viscous liquid (density = 1.5 kg/m^3), find the terminal speed of a sphere of silver (density = 10.5 kg/m^3) of the same size in the same liquid **[2006]**
   (a) 0.4 m/s (b) 0.133 m/s
   (c) 0.1 m/s (d) 0.2 m/s

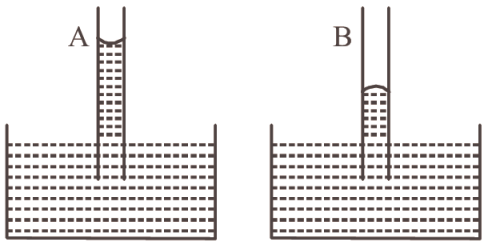
6. A spherical solid ball of volume V is made of a material of density ρ_1. It is falling through a liquid of density ρ_1 ($\rho_2 < \rho_1$). Assume that the liquid applies a viscous force on the ball that is proportional to the square of its speed v, i.e., $F_{viscous} = -kv^2$ ($k > 0$). The terminal speed of the ball is **[2008]**
   (a) $\sqrt{\dfrac{Vg(\rho_1 - \rho_2)}{k}}$ (b) $\dfrac{Vg\rho_1}{k}$
   (c) $\sqrt{\dfrac{Vg\rho_1}{k}}$ (d) $\dfrac{Vg(\rho_1 - \rho_2)}{k}$

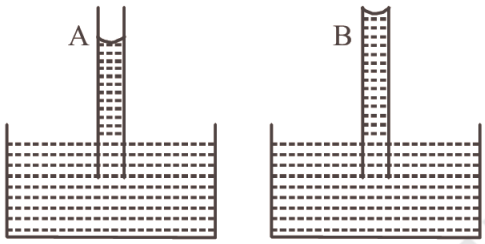
7. A jar is filled with two non-mixing liquids 1 and 2 having densities ρ_1 and, ρ_2 respectively. A solid ball, made of a material of density ρ_3, is dropped in the jar. It comes to equilibrium in the position shown in the figure. Which of the following is true for ρ_1, ρ_2 and ρ_3? **[2008]**

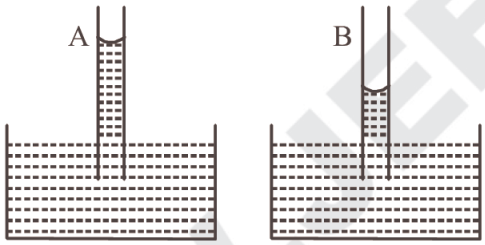


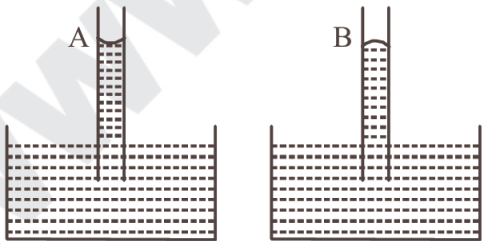
   (a) $\rho_3 < \rho_1 < \rho_2$ (b) $\rho_1 > \rho_3 > \rho_2$
   (c) $\rho_1 < \rho_2 < \rho_3$ (d) $\rho_1 < \rho_3 < \rho_2$

8. A capillary tube (A) is dipped in water. Another identical tube (B) is dipped in a soap-water solution. Which of the following shows the relative nature of the liquid columns in the two tubes? **[2008]**

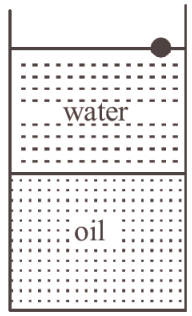
(a)


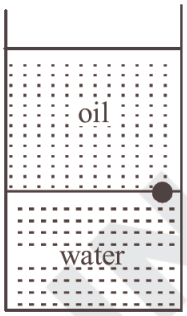
(b)


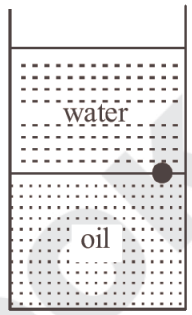
(c)


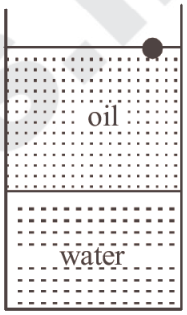
(d)


9. A ball is made of a material of density ρ where $\rho_{oil} < \rho < \rho_{water}$ with ρ_{oil} and ρ_{water} representing the densities of oil and water, respectively. The oil and water are immiscible. If the above ball is in equilibrium in a mixture of this oil and water, which of the following pictures represents its equilibrium position ? **[2010]**

(a)


(b)


(c)


(d)


10. Work done in increasing the size of a soap bubble from a radius of 3 cm to 5 cm is nearly (Surface tension of soap solution = 0.03 Nm^{-1}) **[2011]**

(a) 0.2π mJ (b) 2πmJ
(c) 0.4πmJ (d) 4πmJ

11. Water is flowing continuously from a tap having an internal diameter 8×10^{-3} m. The water velocity as it leaves the tap is 0.4 ms^{-1}. The diameter of the water stream at a distance 2×10^{-1} m below the tap is close to: **[2011]**

(a) 7.5×10^{-3} m (b) 9.6×10^{-3} m
(c) 3.6×10^{-3} m (d) 5.0×10^{-3} m

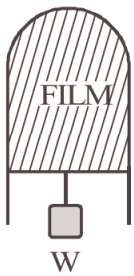
12. Two mercury drops (each of radius 'r') merge to form bigger drop. The surface energy of the bigger drop, if T is the surface tension, is : **[2011 RS]**

(a) $4\pi r^2 T$ (b) $2\pi r^2 T$
(c) $2^{8/3}\pi r^2 T$ (d) $2^{5/3}\pi r^2 T$

13. If a ball of steel (density $\rho = 7.8$ g cm^{-3}) attains a terminal velocity of 10 cm s^{-1} when falling in water (Coefficient of viscosity $\eta_{water} = 8.5 \times 10^{-4}$ Pa.s), then, its terminal velocity in glycerine ($\rho = 1.2$ g cm^{-3}, $\eta = 13.2$ Pa.s) would be, nearly **[2011 RS]**

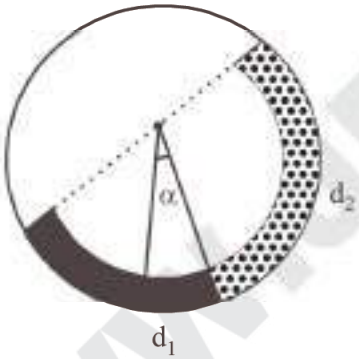
(a) 6.25×10^{-4} cm s^{-1} (b) 6.45×10^{-4} cm s^{-1}
(c) 1.5×10^{-5} cm s^{-1} (d) 1.6×10^{-5} cm s^{-1}

14. A thin liquid film formed between a U-shaped wire and a light slider supports a weight of 1.5×10^{-2} N (see figure). The length of the slider is 30 cm and its weight is negligible. The surface tension of the liquid film is **[2012]**



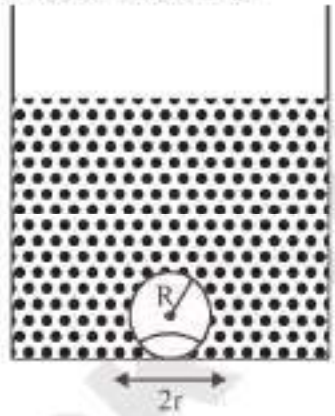
(a) 0.0125 Nm^{-1} (b) 0.1 Nm^{-1}
(c) 0.05 Nm^{-1} (d) 0.025 Nm^{-1}

15. There is a circular tube in a vertical plane. Two liquids which do not mix and of densities d_1 and d_2 are filled in the tube. Each liquid subtends 90º angle at centre. Radius joining their interface makes an angle α with vertical. Ratio $\frac{d_1}{d_2}$ is: **[2014]**



(a) $\frac{1+\sin\alpha}{1-\sin\alpha}$ (b) $\frac{1+\cos\alpha}{1-\cos\alpha}$
(c) $\frac{1+\tan\alpha}{1-\tan\alpha}$ (d) $\frac{1+\sin\alpha}{1-\cos\alpha}$

16. On heating water, bubbles being formed at the bottom of the vessel detach and rise. Take the bubbles to be spheres of radius R and making a circular contact of radius r with the bottom of the vessel. If $r \ll R$ and the surface tension of water is T, value of r just before bubbles detach is: (density of water is ρ_w) **[2014]**



(a) $R^2\sqrt{\frac{2\rho_w g}{3T}}$ (b) $R^2\sqrt{\frac{\rho_w g}{6T}}$
(c) $R^2\sqrt{\frac{\rho_w g}{T}}$ (d) $R^2\sqrt{\frac{3\rho_w g}{T}}$

17. An open glass tube is immersed in mercury in such a way that a length of 8 cm extends above the mercury level. The open end of the tube is then closed and sealed and the tube is raised vertically up by additional 46 cm. What will be length of the air column above mercury in the tube now?
(Atmospheric pressure = 76 cm of Hg) **[2014]**
(a) 16 cm (b) 22 cm
(c) 38 cm (d) 6 cm

18. A man grows into a giant such that his linear dimensions increase by a factor of 9. Assuming that his density remains same, the stress in the leg will change by a factor of **[2017]**

(a) 81 (b) $\frac{1}{81}$ (c) 9 (d) $\frac{1}{9}$

19. If 'M' is the mass of water that rises in a capillary tube of radius 'r', then mass of water which will rise in a capillary tube of radius '2r' is : **[2019]**

(a) M (b) $\frac{M}{2}$ (c) 4 M (d) 2 M

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(b)	(b)	(a)	(c)	(c)	(a)	(d)	(c)	(b)	(c)	(c)	(c)	(a)	(d)	(c)
16	17	18	19											
(a)	(a)	(c)	(d)											

Solutions

1. **(b)** Given, Height of cylinder, h=20 cm
Acceleration due to gravity, g=10 ms^{-2}
Velocity of efflux

$v = \sqrt{2gh}$

Where h is the height of the free surface of liquid from th e hole

$\Rightarrow v = \sqrt{2 \times 10 \times 20} = 20 \text{ m/s}$

2. **(b)** From Stoke's law, force of viscosity acting on a spherical body is

$F = 6\pi\eta r v$

hence F is directly proportional to radius & velocity.

3. **(a)** Let pressure outside be P_0 and r and R be the radius of smaller bubble and bigger bubble respectively.

$\therefore$ Pressure P_1 For smaller bubble $= P_0 + \frac{2T}{r}$

P_2 For bigger bubble $= P_0 + \frac{2T}{R} \quad (R > r)$

$\therefore P_1 > P_2$

hence air moves from smaller bubble to bigger bubble.

4. **(c)** Water fills the tube entirely in gravityless condition i.e., 20 cm.

5. **(c)** Given,
Density of gold, $\rho_G = 19.5 \text{ kg/m}^3$
Density of silver, $\rho_5 = 10.5 \text{kg/m}^3$
Density of liquid, $\sigma = 1.5 \text{kg/m}^3$

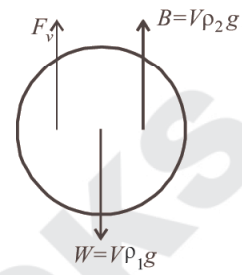
Terminal velocity, $v_T = \frac{2r^2(\rho - \sigma)g}{9\eta}$

$\therefore \frac{v_{T_2}}{0.2} = \frac{(10.5 - 1.5)}{(19.5 - 1.5)}$

$\Rightarrow v_{T_2} = 0.2 \times \frac{9}{18}$

$\therefore v_{T_2} = 0.1 \text{ m/s}$

6. **(a)** When the ball attains terminal velocity
Weight of the ball = Buoyant force + Viscous force



$\therefore V\rho_1 g = V\rho_2 g + kv_t^2 \Rightarrow Vg(\rho_1 - \rho_2)g = kv_t^2$

$\Rightarrow v_t = \sqrt{\frac{Vg(\rho_1 - \rho_2)}{k}}$

7. **(d)** As liquid 1 floats over liquid 2. The lighter liquid floats over heavier liquid. So,

$\rho_1 < \rho_2$

Also $\rho_3 < \rho_2$ because the ball of density ρ_3 does not sink to the bottom of the jar. Also $\rho_3 > \rho_1$ otherwise the ball would have floated in liquid 1. we conclude that

$\rho_1 < \rho_3 < \rho_2$.

8. **(c)** In case of water, the meniscus shape is concave upwards. From ascent formula

$h = \frac{2\sigma\cos\theta}{r\rho g}$

The surface tension (σ) of soap solution is less than water. Therefore height of capillary rise for soap solution should be less as compared to water. As in the case of water, the meniscus shape of soap solution is also concave upwards.

9. **(b)** Oil will float on water so, (b) or (d) is the correct option. But density of ball is more than that of oil,, hence it will sink in oil.

10. **(c)** Work done = increase in surface area × surface tension

$\Rightarrow W = 2T4\pi[(5^2) - (3)^2] \times 10^{-4}$
$= 2 \times 0.03 \times 4\pi\,[25 - 9] \times 10^{-4} \text{ J}$
$= 0.4\pi \times 10^{-3} \text{ J} = 0.4\pi \text{ mJ}$

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11. **(c)** Using Bernoulli's theorem, for horizontal flow

$$P_0 + \frac{1}{2}\rho v_1^2 + \rho g h = P_0 + \frac{1}{2}\rho v_2^2 + 0$$

$$v_2 = \sqrt{v_1^2 + 2gh} = \sqrt{0.16 + 2 \times 10 \times 0.2} = 2.03 \text{ m/s}$$

According to equation of continuity

$$A_2 v_2 = A_1 v_1$$

$$\pi \frac{D_2^2}{4} \times v_2 = \pi \frac{D_1^2}{4} v_1$$

$$\Rightarrow D_2 = D_1 \sqrt{\frac{v_1}{v_2}} = 3.55 \times 10^{-3} \text{ m}$$

12. **(c)** As volume remains constant

$\therefore$ Sum of volumes of 2 smaller drops = Volume of the bigger drop

$$2.\frac{4}{3}\pi r^3 = \frac{4}{3}\pi R^3 \Rightarrow R = 2^{1/3}\, r$$

Surface energy = Surface tension × Surface area = $T.4\pi R^2$

$$= T4\pi 2^{2/3} r^2 = T.2^{8/3}\pi r^2.$$

13. **(a)** When the ball attains terminal velocity

Weight of the ball = viscous force + buoyant force

$$\therefore V\rho g = 6\pi\eta r v + V\rho_\ell g$$

$$\Rightarrow Vg(\rho - \rho_\ell) = 6\pi\eta r v$$

Also $Vg\left(\rho - \rho_i'\right) = 6\pi\eta' r v'$

$$\therefore \quad v'\eta' = \frac{(\rho - \rho_\ell')}{(\rho - \rho_\ell)} \times v\eta$$

$$\Rightarrow v' = \frac{(\rho - \rho_\ell')}{(\rho - \rho_\ell)} \times \frac{v\eta}{\eta'}$$

$$= \frac{(7.8 - 1.2)}{(7.8 - 1)} \times \frac{10 \times 8.5 \times 10^{-4}}{13.2}$$

$$\therefore \quad v' = 6.25 \times 10^{-4} \text{ cm/s}$$

14. **(d)** Let T is the force due to surface tension per unit length, then

F = 2*l*T

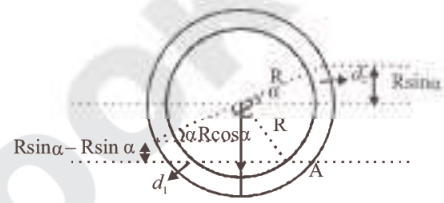
l = length of the slider.

At equilibrium, $F = W$

$\therefore 2Tl = mg$

$$\Rightarrow T = \frac{mg}{2l} = \frac{1.5 \times 10^{-2}}{2 \times 30 \times 10^{-2}} = \frac{1.5}{60} = 0.025 \text{ Nm}^{-1}$$

15. **(c)** Pressure at interface A must be same from both the sides to be in equilibrium.



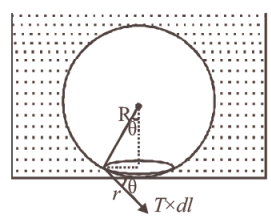
$$\therefore \quad (R\cos\alpha + R\sin\alpha)d_2 g$$

$$= (R\cos\alpha - R\sin\alpha)d_1 g$$

$$\Rightarrow \frac{d_1}{d_2} = \frac{\cos\alpha + \sin\alpha}{\cos\alpha - \sin\alpha} = \frac{1 + \tan\alpha}{1 - \tan\alpha}$$

16. **(a)** When the bubble gets detached,

Buoyant force = force due to surface tension



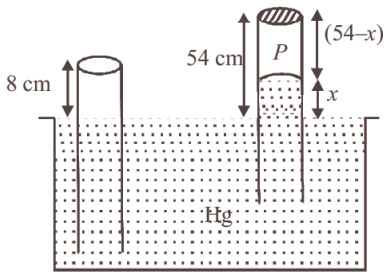
Force due to excess pressure = upthrust

Access pressure in air bubble = $\frac{2T}{R}$

$$\frac{2T}{R}(\pi r^2) = \frac{4\pi R^3}{3T}\rho_w g$$

$$\Rightarrow r^2 = \frac{2R^4 \rho_w g}{3T} \Rightarrow r = R^2\sqrt{\frac{2\rho_w g}{3T}}$$

17. (a)



Length of the air column above mercury in the tube is,

$P + x = P_0$

$\Rightarrow \quad P = (76 - x)$

$\Rightarrow \quad 8 \times A \times 76 = (76 - x) \times A \times (54 - x)$

$\therefore \quad x = 38$

Thus, length of air column

$= 54 - 38 = 16$ cm.

18. (c) As linear dimension increases by a factor of 9

$\therefore \quad \frac{v_f}{v_i} = 9^3$

$\because$ Density remains same

So, mass $\propto$ Volume

$$\frac{m_f}{m_i} = 9^3 \quad \Rightarrow \quad \frac{(Area)_f}{(Area)_i} = 9^2$$

$$\text{Stress } (\sigma) = \frac{force}{area} = \frac{(mass) \times g}{area}$$

$$\frac{\sigma_2}{\sigma_1} = \left(\frac{m_f}{m_i}\right)\left(\frac{A_i}{A_f}\right) = \frac{9^3}{9^2} = 9$$

19. (d) We have, $h = \frac{2T\cos\theta}{r\rho g}$

Mass of the water in the capillary

$$m = \rho V = \rho \cdot \pi r^2 h = \rho \times \pi r^2 \times \frac{2T\cos\theta}{r\rho g}$$

$\Rightarrow m \alpha r$

$\therefore \frac{m_1}{m_2} = \frac{r}{2r}$

or, $m_2 = 2m_1 = 2m$

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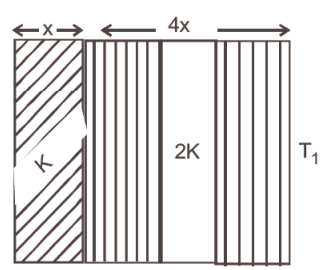
Thermal Properties of Matter

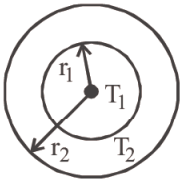
10

1. Heat given to a body which raises its temperature by 1°C is **[2002]**
   (a) water equivalent
   (b) thermal capacity
   (c) specific heat
   (d) temperature gradient
2. Infrared radiation is detected by **[2002]**
   (a) spectrometer (b) pyrometer
   (c) nanometer (d) photometer
3. Which of the following is more close to a black body? **[2002]**
   (a) black board paint
   (b) green leaves
   (c) black holes
   (d) red roses
4. If mass-energy equivalence is taken into account, when water is cooled to form ice, the mass of water should **[2002]**
   (a) increase
   (b) remain unchanged
   (c) decrease
   (d) first increase then decrease
5. Two spheres of the same material have radii 1 m and 4 m and temperatures 4000 K and 2000 K respectively. The ratio of the energy radiated per second by the first sphere to that by the second is **[2002]**
   (a) 1 : 1 (b) 16 : 1 (c) 4 : 1 (d) 1 : 9.
6. The earth radiates in the infra-red region of the spectrum. The spectrum is correctly given by **[2003]**
   (a) Rayleigh Jeans law
   (b) Planck's law of radiation
   (c) Stefan's law of radiation
   (d) Wien's law
7. According to Newton's law of cooling, the rate of cooling of a body is proportional to $(\Delta\theta)^n$, where $\Delta\theta$ is the difference of the temperature of the body and the surroundings, and n is equal to **[2003]**
   (a) two (b) three
   (c) four (d) one
8. If the temperature of the sun were to increase from T to $2T$ and its radius from R to $2R$, then the ratio of the radiant energy received on earth to what it was previously will be **[2004]**
   (a) 32 (b) 16 (c) 4 (d) 64
9. The temperature of the two outer surfaces of a composite slab, consisting of two materials having coefficients of thermal conductivity K and $2K$ and thickness x and $4x$, respectively, are T_2 and $T_1 (T_2 > T_1)$. The rate of heat transfer through the slab, in a steady state is $\left(\frac{A(T_2 - T_1)K}{x}\right) f$, with f equal to **[2004]**



   (a) $\frac{2}{3}$ (b) $\frac{1}{2}$ (c) 1 (d) $\frac{1}{3}$

10. The figure shows a system of two concentric spheres of radii r_1 and r_2 are kept at temperatures T_1 and T_2, respectively. The radial rate of flow of heat in a substance between the two concentric spheres is proportional to **[2005]**



(a) $\ell n\left(\frac{r_2}{r_1}\right)$ (b) $\frac{(r_2 - r_1)}{(r_1 r_2)}$

(c) $(r_2 - r_1)$ (d) $\frac{r_1 r_2}{(r_2 - r_1)}$

11. Assuming the Sun to be a spherical body of radius R at a temperature of TK, evaluate the total radiant powerd incident of Earth at a distance r from the Sun **[2006]**

(a) $4\pi r_0^2 R^2 \sigma \frac{T^4}{r^2}$ (b) $\pi r_0^2 R^2 \sigma \frac{T^4}{r^2}$

(c) $r_0^2 R^2 \sigma \frac{T^4}{4\pi r^2}$ (d) $R^2 \sigma \frac{T^4}{r^2}$

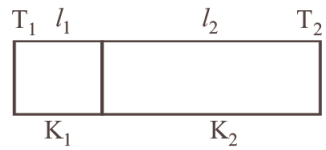
where r_0 is the radius of the Earth and σ is Stefan's constant.

12. Two rigid boxes containing different ideal gases are placed on a table. Box A contains one mole of nitrogen at temperature T_0, while Box contains one mole of helium at temperature $\left(\frac{7}{3}\right)T_0$. The boxes are then put into thermal contact with each other, and heat flows between them until the gases reach a common final temperature (ignore the heat capacity of boxes). Then, the final temperature of the gases, T_f in terms of T_0 is **[2006]**

(a) $T_f = \frac{3}{7}T_0$ (b) $T_f = \frac{7}{3}T_0$

(c) $T_f = \frac{3}{2}T_0$ (d) $T_f = \frac{5}{2}T_0$

13. One end of a thermally insulated rod is kept at a temperature T_1 and the other at T_2. The rod is composed of two sections of length l_1 and l_2 and thermal conductivities K_1 and K_2 respectively. The temperature at the interface of the two section is **[2007]**



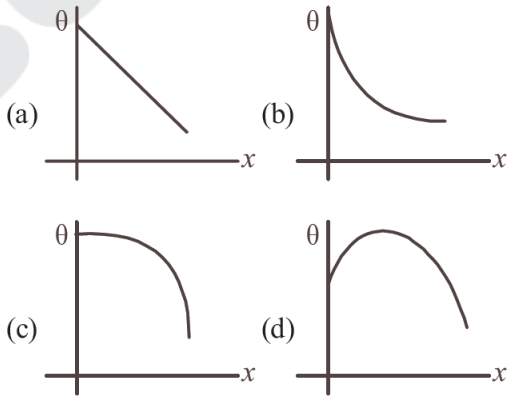
(a) $\frac{(K_1 l_1 T_1 + K_2 l_2 T_2)}{(K_1 l_1 + K_2 l_2)}$

(b) $\frac{(K_2 l_2 T_1 + K_1 l_1 T_2)}{(K_1 l_1 + K_2 l_2)}$

(c) $\frac{(K_2 l_1 T_1 + K_1 l_2 T_2)}{(K_2 l_1 + K_1 l_2)}$

(d) $\frac{(K_1 l_2 T_1 + K_2 l_1 T_2)}{(K_1 l_2 + K_2 l_1)}$

14. A long metallic bar is carrying heat from one of its ends to the other end under steady–state. The variation of temperature θ along the length x of the bar from its hot end is best described by which of the following figures? **[2009]**



15. 100g of water is heated from 30°C to 50°C. Ignoring the slight expansion of the water, the change in its internal energy is (specific heat of water is 4184 J/kg/K): **[2011]**

(a) 8.4 kJ (b) 84 kJ

(c) 2.1 kJ (d) 4.2 kJ

16. The specific heat capacity of a metal at low temperature (T) is given as

$$C_p(kJK^{-1}\text{kg}^{-1}) = 32\left(\frac{T}{400}\right)^3$$

A 100 gram vessel of this metal is to be cooled from 20ºK to 4ºK by a special refrigerator operating at room temperature (27°C). The amount of work required to cool the vessel is **[2011 RS]**

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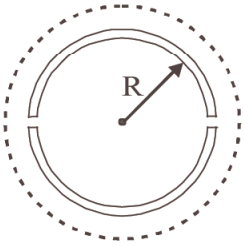
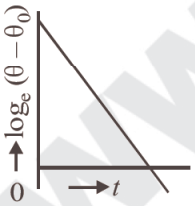
(a) greater than 0.148 kJ
(b) between 0.148 kJ and 0.028 kJ
(c) less than 0.028 kJ
(d) equal to 0.002 kJ

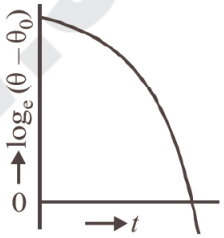
17. A wooden wheel of radius R is made of two semicircular part (see figure). The two parts are held together by a ring made of a metal strip of cross sectional area S and length L. L is slightly less than $2\pi R$. To fit the ring on the wheel, it is heated so that its temperature rises by ΔT and it just steps over the wheel. As it cools down to surrounding temperature, it presses the semicircular parts together. If the coefficient of linear expansion of the metal is α, and its Young's modulus is Y, the force that one part of the wheel applies on the other part is : **[2012]**

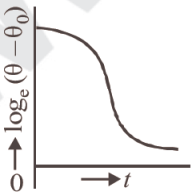


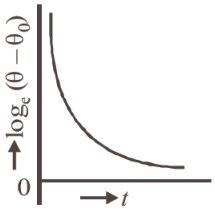
(a) $2\pi SY\alpha\Delta T$ (b) $SY\alpha\Delta T$
(c) $\pi SY\alpha\Delta T$ (d) $2SY\alpha\Delta T$

18. A liquid in a beaker has temperature $\theta(t)$ at time t and θ_0 is temperature of surroundings, then according to Newton's law of cooling the correct graph between $\log_e(\theta - \theta_0)$ and t is : **[2012]**

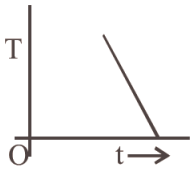
(a)


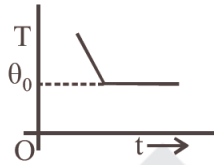
(b)


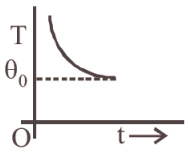
(c)


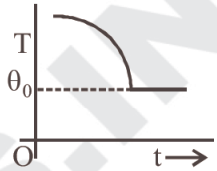
(d)


19. If a piece of metal is heated to temperature θ and then allowed to cool in a room which is at temperature θ_0, the graph between the temperature T of the metal and time t will be closest to **[2013]**

(a)


(b)


(c)


(d)


20. Three rods of Copper, Brass and Steel are welded together to form a Y shaped structure. Area of cross - section of each rod = 4 cm^2. End of copper rod is maintained at 100ºC where as ends of brass and steel are kept at 0ºC. Lengths of the copper, brass and steel rods are 46, 13 and 12 cms respectively. The rods are thermally insulated from surroundings excepts at ends. Thermal conductivities of copper, brass and steel are 0.92, 0.26 and 0.12 CGS units respectively. Rate of heat flow through copper rod is: **[2014]**

(a) 1.2 cal/s (b) 2.4 cal/s
(c) 4.8 cal/s (d) 6.0 cal/s

21. Consider a spherical shell of radius R at temperature T. The black body radiation inside it can be considered as an ideal gas of photons with internal energy per unit volume $u = \frac{U}{V} \propto T^4$ and pressure $p = \frac{1}{3}\left(\frac{U}{V}\right)$. If the shell now undergoes an adiabatic expansion the relation between T and R is : **[2015]**

(a) $T \propto \frac{1}{R}$ (b) $T \propto \frac{1}{R^3}$
(c) $T \propto e^{-R}$ (d) $T \propto e^{-3R}$

22. A pendulum clock loses 12 s a day if the temperature is 40°C and gains 4 s a day if the temperature is 20°C. The temperature at which the clock will show correct time, and the co-efficient of linear expansion (α) of the metal of the pendulum shaft are respectively : **[2016]**

(a) 30°C; $\alpha = 1.85 \times 10^{-3}$/°C
(b) 55°C; $\alpha = 1.85 \times 10^{-2}$/°C
(c) 25°C; $\alpha = 1.85 \times 10^{-5}$/°C
(d) 60°C; $\alpha = 1.85 \times 10^{-4}$/°C