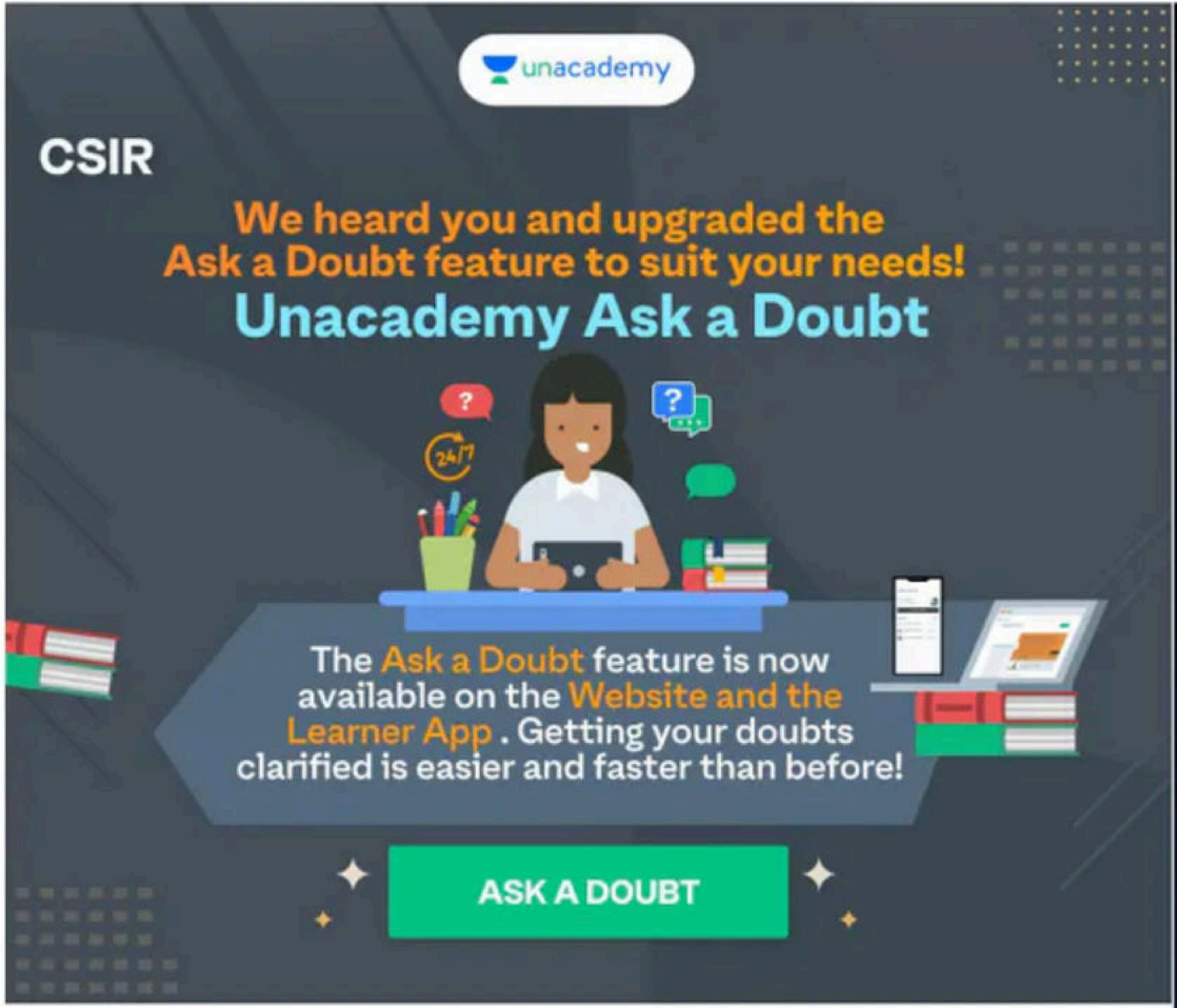
Integral Calculus - Part III

Detailed Course on Integral Calculus - IIT JAM' 23

Gajendra Purohit • Lesson 3 • July 11, 2022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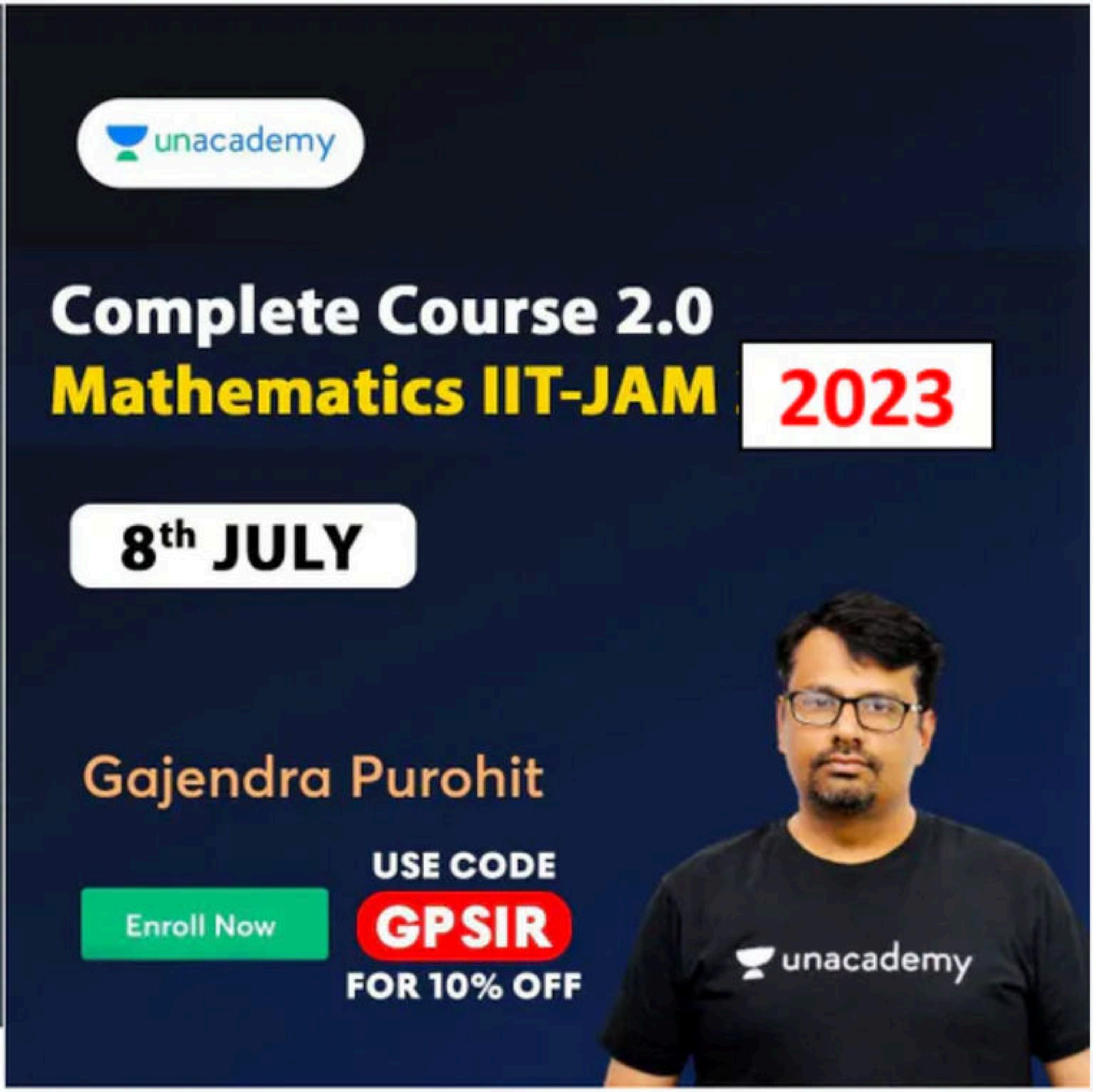
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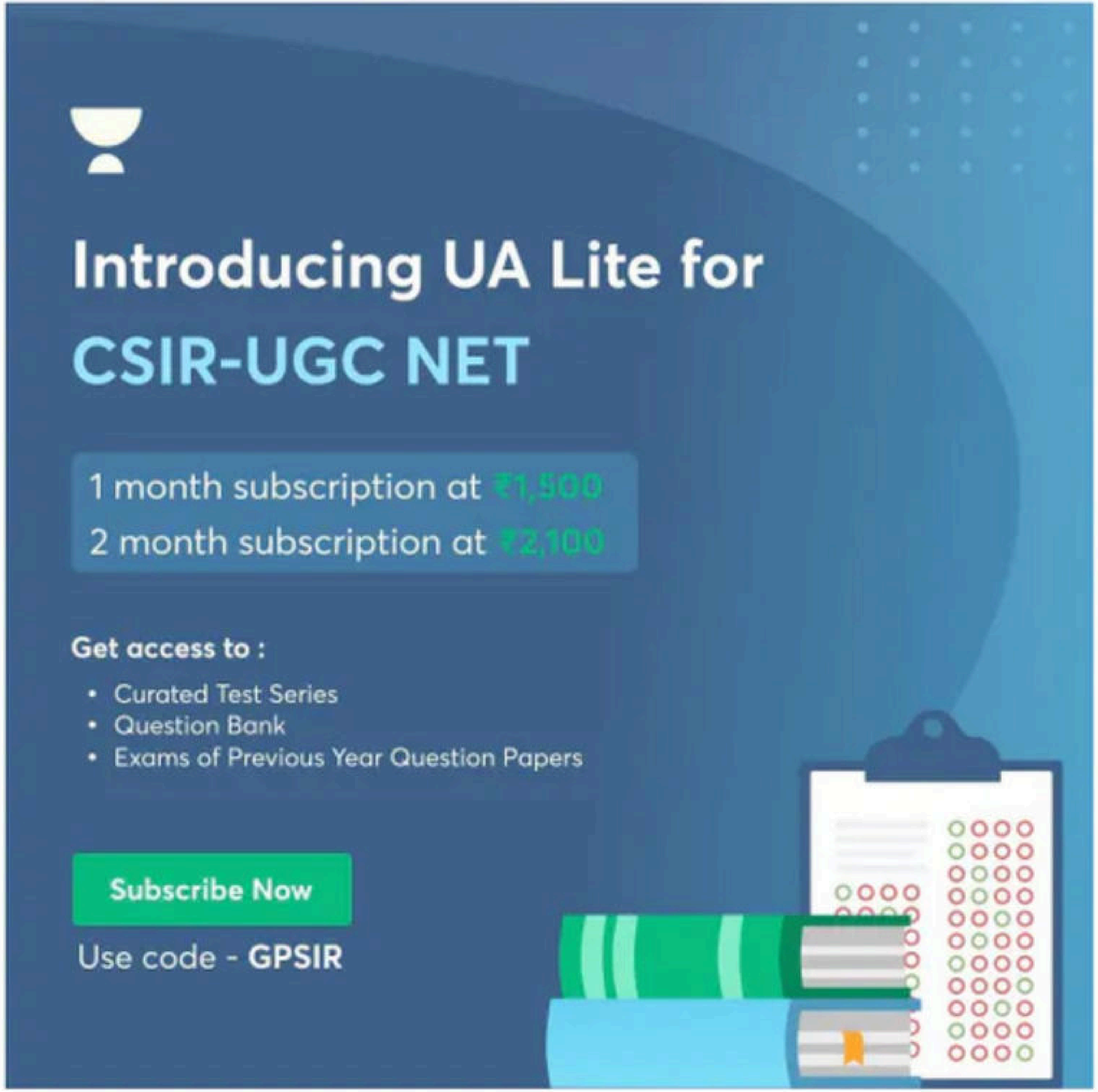
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$$\int_0^\infty x^2 e^{-x}\,dx = 2 = 2!$$

$$\int_0^\infty x^3 e^{-x}\,dx = 6 = 3!$$
$$= 3\times 2\times 1$$

$$\int_0^\infty x^5 e^{-x}\,dx = 120 = 5!$$
$$5! = 5\times 4\times 3\times 2\times 1$$

$$\int_0^\infty x^{n-1} e^{-x}\,dx = \Gamma n = (n-1)!$$

$$\left(x^2 \int e^{-x}dx - \int \left(\frac{d(x^2)}{dx} \int e^{-x}dx\right)dx\right)_0^\infty$$

$$\left(-x^2 e^{-x} + \int 2x e^{-x}dx\right)_0^\infty$$

$$\left(-x^2 e^{-x} + 2\left(x \int e^{-x}dx - \int \left(\frac{d(x)}{dx} \int e^{-x}dx\right)dx\right)\right)_0^\infty$$

$$\left[-x^2 e^{-x} + 2\left(-x e^{-x} - e^{-x}\right)\right]_0^\infty$$

$$(0 + 2(0-0)) - (0 + 2(-0-1))$$
$$= 2$$

$$e^{-\infty} = 0$$

$$\int_0^\infty x^{3/2} e^{-x}\,dx = \Gamma\tfrac{5}{2}$$

$$\Gamma\tfrac{1}{2} = \sqrt{\pi}$$

$$\int_0^\infty x^{n-1} e^{-x}\,dx = \Gamma n$$

$$= \frac{3}{4}\sqrt{\pi}$$

$$\Gamma\tfrac{5}{2} = \frac{3}{2}\cdot\frac{1}{2}\Gamma\tfrac{1}{2} = \frac{3}{4}\sqrt{\pi}$$

$$\int_0^\infty x^{5/2} e^{-x}\,dx = \Gamma\tfrac{7}{2} = \frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{2}\Gamma\tfrac{1}{2} = \frac{15}{8}\sqrt{\pi}$$

$$\int_{x=0}^{\infty} x^7 e^{-4\sqrt{x}}\,dx$$

$$\int x^{n-1} e^{-\lambda x}\,dx = \frac{\Gamma n}{\lambda^n}$$

Let $4\sqrt{x} = t$

$dx = dt/4$

$$\int_{t=0}^{\infty} \left(\frac{t}{4}\right)^7 e^{-t}\,\frac{dt}{4} = \frac{1}{4^8}\int_0^{\infty} t^7 e^{-t}\,dt = \frac{\Gamma 8}{4^8}$$

$$\int_0^\infty (x)^{1/4} e^{-\sqrt{x}}\, dx$$

(a) $\frac{1}{2}\sqrt{\pi}$

(b) $\frac{3}{2}\sqrt{\pi}$

(c) $\frac{5}{4}\sqrt{\pi}$

(d) $\sqrt{\pi}$

$$\int_0^\infty t^{n-1} e^{-t}\, dt = \Gamma n$$

Let $\sqrt{x} = t$

$x = t^2$

$dx = 2t\, dt$

$$\int_0^\infty (t^2)^{1/4} e^{-t}\, 2t\, dt$$

$$2\int_0^\infty t^{3/2} e^{-t}\, dt = 2\Gamma 5/2$$

$t^{1/2+1}$

$$= \cancel{2} \times \frac{3}{\cancel{2}} \frac{1}{2} \Gamma \tfrac{1}{2}$$

$$= \frac{3}{2}\sqrt{\pi}$$

$$\int_0^\infty e^{-x^2}\,dx$$

(a) $\frac{1}{2}\sqrt{\pi}$

(b) $\frac{3}{2}\sqrt{\pi}$

(c) $5/2\sqrt{\pi}$

(d) $\sqrt{\pi}$

$x^2 = t \quad 2x\,dx = dt$

$dx = \frac{dt}{2x}$

$dx = \frac{dt}{2\sqrt{t}}$

$$\int_0^\infty e^{-t}\frac{dt}{2\sqrt{t}}$$

$$\frac{1}{2}\int_0^\infty t^{-1/2}e^{-t}\,dt$$

$$\frac{1}{2}\Gamma\tfrac{1}{2} = \frac{\sqrt{\pi}}{2}$$

$$\int_0^\infty y^{1/2} e^{-y^3}\, dy$$

$y^3 = t$ $\qquad$ $y = (t)^{1/3}$

$3y^2\, dy = dt$

$dy = \frac{dt}{3y^2}$

$dy = \frac{dt}{3t^{2/3}}$

(a) $\frac{\sqrt{\pi}}{2}$ $\qquad$ (b) $\frac{3}{2}\sqrt{\pi}$

(c) $\frac{\sqrt{\pi}}{3}$ $\qquad$ (d) $\frac{5\sqrt{\pi}}{2}$

$$\int_0^\infty t^{1/6} e^{-t} \frac{dt}{3t^{2/3}} = \frac{1}{3}\int_0^\infty t^{1/6-2/3} e^{-t}\, dt = \frac{1}{3}\int_0^\infty t^{-1/2} e^{-t}\, dt$$

$$= \frac{1}{3}\Gamma\left(\tfrac{1}{2}\right) = \frac{\sqrt{\pi}}{3}$$

Gamma Function:

If m and n are non-negative integers, then

$$\int_0^{\pi/2} \sin^m x \cos^n x dx = \frac{\Gamma\left(\frac{m+1}{2}\right)\Gamma\left(\frac{n+1}{2}\right)}{2\Gamma\left(\frac{m+n+2}{2}\right)}$$

where $\Gamma(n)$ is called gamma function which satisfied the following properties

$\Gamma(n+1) = n\Gamma(n) = n!$ $\quad$ *i.e.* $\Gamma(1) = 1$ and $\Gamma(1/2) = \sqrt{\pi}$

Q.1. Evaluate $\int_{0}^{\infty} x^{1/4} e^{-\sqrt{x}} dx$

(a) $2\sqrt{\pi}$

(b) $\frac{3}{2}\pi$

(c) $\sqrt{\pi}$

(d) $\frac{3}{2}\sqrt{\pi}$

Q2. If $I_n = \int_0^\infty e^{-x} x^{n-1} dx$, then $\int_0^\infty e^{-\lambda x} x^{n-1} dx$ is equal to

$\frac{\Gamma n}{\lambda n}$ $\frac{I_n}{\lambda n}$

Γn

(a) λI_n

(b) $\frac{1}{\lambda} I_n$

(c) $\frac{I_n}{\lambda^n}$

(d) $\lambda^n I_n$

Q.3. Let a,b be positive real numbers such that a < b Given that

$\lim_{n\to\infty}\int_0^n e^{-t^2}dt = \frac{\sqrt{\pi}}{2}$ Then value of $\lim_{n\to\infty}\int_0^n \frac{1}{t^2}\left(e^{-at^2}-e^{-bt^2}\right)dt$ is

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(a) $\sqrt{\pi}\left(\sqrt{b}-\sqrt{a}\right)$ (b) $\sqrt{\pi}\left(\sqrt{b}+\sqrt{a}\right)$

(c) $-\sqrt{\pi}\left(\sqrt{b}-\sqrt{a}\right)$ (d) $\sqrt{\pi}\left(-\sqrt{b}+\sqrt{a}\right)$

$\Gamma n\,\Gamma(1-n) = \frac{\pi}{\sin n\pi}$

$\Gamma\tfrac{1}{2}\,\Gamma\tfrac{3}{2} = \frac{\pi}{\sin(-\pi/2)}$

$\Gamma{-\tfrac{1}{2}}\left(\tfrac{1}{2}\Gamma\tfrac{1}{2}\right) = \frac{\pi}{-\sin\pi/2} \Rightarrow \Gamma{-\tfrac{1}{2}}\,\frac{\sqrt{\pi}}{2} = -\pi$

$\Gamma{-\tfrac{1}{2}} = -2\sqrt{\pi}$

$at^2 = p$

$t^2 = p/a$

$t = \frac{\sqrt{p}}{\sqrt{a}}$

$dt = \frac{1}{2\sqrt{p}\sqrt{a}}dp$

$$\int_0^\infty \frac{e^{-at^2}}{t^2}dt = \int_0^\infty \frac{e^{-p}}{(p/a)}\frac{dp}{2\sqrt{p}\sqrt{a}} = \frac{\sqrt{a}}{2}\int_0^\infty \frac{e^{-p}}{p^{3/2}}dp$$

$$= \frac{\sqrt{a}}{2}\int_0^\infty p^{-3/2}e^{-p}dp = \frac{\sqrt{a}}{2}\Gamma{-\tfrac{1}{2}} = \frac{\sqrt{a}}{2}(-2\sqrt{\pi}) = -\sqrt{a}\sqrt{\pi}$$

$$\int_0^\infty \frac{e^{-bt^2}}{t^2}dt = -\sqrt{b}\sqrt{\pi}$$

$-\sqrt{a}\sqrt{\pi} + \sqrt{b}\sqrt{\pi}$

$\sqrt{\pi}(\sqrt{b}-\sqrt{a})$

$$\int_0^{\pi/2} \sin^p\theta \cos^q\theta \, d\theta = \frac{\Gamma\frac{p+1}{2}\,\Gamma\frac{q+1}{2}}{2\,\Gamma\frac{p+q+2}{2}}$$

$$\int_0^{\pi/2} \sin^3\theta \cos^2\theta \, d\theta = \frac{\Gamma\frac{4}{2}\,\Gamma\frac{3}{2}}{2\,\Gamma\frac{7}{2}} = \frac{\Gamma 2\,\cancel{\frac{1}{2}}\,\cancel{\Gamma\frac{1}{2}}}{\cancel{2}\left(\cancel{\frac{5}{2}}\,\frac{3}{2}\,\cancel{\frac{1}{2}}\,\cancel{\Gamma\frac{1}{2}}\right)}$$

$$= \frac{2\,\Gamma 2}{15} = \frac{2}{15}$$

$$\int_0^{\pi/2} \sin^7\theta \, d\theta = \int_0^{\pi/2} \sin^7\theta \cos^0\theta \, d\theta$$

$$= \frac{\Gamma\frac{7+1}{2}\,\Gamma\frac{0+1}{2}}{2\,\Gamma\frac{9}{2}} = \frac{\Gamma 4 \; \cancel{\sqrt{\pi}}}{\cancel{2}\;\cancel{\Gamma\frac{7}{2}}\cdot\frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{2}\cdot\left(\cancel{\sqrt{\pi}}\right)}$$

$$= \frac{\cancel{6}\times 8}{7\times 5\times \cancel{3}} = \frac{16}{35}$$

$$\int_0^{\pi/2} \sqrt{\cot\theta}\, d\theta = \int_0^{\pi/2} \frac{\sqrt{\cos\theta}}{\sqrt{\sin\theta}}\, d\theta$$

$$\int_0^{\pi/2} \sin^{-1/2}\theta \cos^{1/2}\theta\, d\theta = \frac{\Gamma\frac{1}{4}\,\Gamma\frac{3}{4}}{2\,\Gamma 1} = \frac{1}{2}\left(\Gamma\tfrac{1}{4}\,\Gamma\tfrac{3}{4}\right) = \frac{\sqrt{2}\pi}{2}$$

$$= \frac{\pi}{\sqrt{2}}$$

$$\Gamma n\, \Gamma 1-n = \frac{\pi}{\sin n\pi}$$

$$n = 1/4$$

$$\Gamma\tfrac{1}{4}\,\Gamma 1-\tfrac{1}{4} = \frac{\pi}{\sin \pi/4}$$

$$\Gamma\tfrac{1}{4}\,\Gamma\tfrac{3}{4} = \sqrt{2}\pi$$

$$\int_0^{\pi/6} \sin 6\theta \cos 3\theta \, d\theta$$

Let $3\theta = t$

$3\,d\theta = dt$

$d\theta = dt/3$

$$\int_0^{\pi/2} \underline{\sin 2t} \cos t \, \frac{dt}{3}$$

$t = 0$

$$\frac{1}{3}\int_0^{\pi/2} 2\sin t \cos t \cos t \, dt = \frac{2}{3}\int_0^{\pi/2} \sin^1 t \cos^2 t \, dt$$

$$= \frac{\cancel{2}}{3}\left(\frac{\Gamma\frac{2}{2}\,\Gamma\frac{3}{2}}{\cancel{2}\,\Gamma\frac{7}{2}}\right) = \frac{1}{3}\,\frac{\cancel{\frac{1}{2}\sqrt{\tfrac{1}{2}}}}{\frac{5}{2}\,\frac{3}{2}\,\cancel{\Gamma\frac{1}{2}}} = \underline{\frac{2}{9}}$$

$$\int_0^{\pi/2} \frac{d\theta}{\sqrt{\sin\theta}} \times \int_0^{\pi/2} \sqrt{\sin\theta}\, d\theta$$

(a) $\sqrt{\pi}$ (b) π

(c) $2\sqrt{\pi}$ (d) 2π

$$\int_0^{\pi/2} \sin^{-1/2}\theta \cos^0\theta\, d\theta$$

$$\frac{\Gamma\frac{1}{4}\,\Gamma\frac{1}{2}}{2\,\cancel{\Gamma\frac{3}{4}}}$$

$$\int_0^{\pi/2} \sin^{1/2}\theta \cos^0\theta\, d\theta$$

$$\frac{\cancel{\Gamma\frac{3}{4}}\,\Gamma\frac{1}{2}}{2\,\Gamma\frac{5}{4}}$$

$$\frac{\cancel{\Gamma\frac{1}{4}}\;\pi}{\cancel{4}\;\frac{1}{\cancel{4}}\;\cancel{\Gamma\frac{1}{4}}} = \pi$$

$$\Gamma n = (n-1)\,\Gamma(n-1)$$

$\Gamma\left(-\frac{3}{2}\right)$ $\quad n = -3/2$

$\Gamma\left(\frac{1}{2}\right)$

$$\Gamma(n)\,\Gamma(1-n) = \frac{\pi}{\sin n\pi}$$

$$\Gamma\left(-\tfrac{3}{2}\right)\Gamma\left(1+\tfrac{3}{2}\right) = \frac{\pi}{\sin\left(-3\pi/2\right)}$$

$$\Gamma\left(-\tfrac{3}{2}\right)\Gamma\left(\tfrac{5}{2}\right) = \frac{\pi}{-\sin\left(\pi+\pi/2\right)}$$

$$\Gamma\left(-\tfrac{3}{2}\right)\left(\tfrac{3}{2}\cdot\tfrac{1}{2}\,\Gamma\left(\tfrac{1}{2}\right)\right) = \frac{\pi}{+\sin\pi/2}$$

$$\Gamma\left(-3/2\right)\,\tfrac{3}{4}\sqrt{\pi} = \frac{\pi}{+1}$$

$$\Gamma\left(-3/2\right) = +\frac{4\sqrt{\pi}}{3}$$

Q4. The value of $\int_0^{\pi/2} \sin^4 x \cos^6 x dx$

(a) $3\pi/312$

(b) $5\pi/512$

(c) $3\pi/512$

(d) $5\pi/312$

$$\frac{\Gamma\frac{5}{2}\,\Gamma\frac{7}{2}}{2\,\Gamma\frac{12}{2}}$$

$$\frac{\left(\frac{3}{2}\cdot\frac{1}{2}\Gamma\frac{1}{2}\right)\left(\frac{5}{2}\cdot\frac{3}{2}\cdot\frac{1}{2}\Gamma\frac{1}{2}\right)}{2\times5\times4\times3\times2\times1}$$

$$\frac{3\cdot5\pi}{32\times2\times5\times4\times3\times2\times1}$$

$$\frac{3\pi}{32\times16}$$

Q5. $\int_0^{\pi/2} \sin^7 x\,dx$ has value

(a) $\frac{37}{184}$

(b) $\frac{17}{45}$

(c) $\frac{16}{35}$

(d) $\frac{16}{45}$

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Tracing of curve

(1) Tracing of cartisiancurve :

(a) Symmetric :

(i) If f(x, y) be a given curve and the power of x is even then it is symmetric about y- axis.

(ii) If f(x, y) be a given curve and the power of y is even power then it is symmetric about x-axis.

(iii) If power of x & y both even then this curve is symmetric about x & y axis.

(b) Curve passing through origin :

If $f(x, y)$ be a given curve and $f(0, 0) = 0$ then this curve passes through origin.

(c) Intersection with coordinate axis :

(i) If we put $y = 0$ in given curve then we get

intersection point of curve and x-axis.

(ii) If we put $x = 0$ in given curve we get intersection point of curve and y-axis

(d) **Asymtote :**

If f(x, y) is a curve

(i) At $x = a$, if we get $y = \infty$, then Asymtote is parallel to y-axis.

(ii) At $y = a$, if we get $x = \infty$, then Asymtote is parallel to x-axis.

Curve tracing of polar form :

(1) Symmetry :

(i) If $f(r, \theta) = f(r, -\theta)$

Then this curve is symmetric about initially line (i.e. $\theta = 0$ line)

(ii) If $f(r, \theta) = f(r, \pi - \theta)$

Then this curve is symmetric about $\theta = \frac{\pi}{2}$ line.

(iii) **Pole :** Put $r = 0$, then find value of θ.

Hence (r, θ) is a pole.

(iv) **Tangent at pole :** Put $r = 0$, then value of θ is tangent at pole.

(v) **Table :**

r									
θ	0	30	45	60	90	120	135	150	180

(vi) **Asymtotes :**

For any value of θ if r become ∞, then a curve has asymtotes.

Q.1. The curve $ay^2 = x^2 (a - x)$ is passing through

(a) (0, 1) (b) (0, 0)

(c) (1, 0) (d) (1, 2)

Q.2. The cardiod $r = a(1 + \cos\theta)$ is symmetric about

(a) $\theta = 0$ line (b) $\theta = \pi/4$ line

(c) $\theta = \pi/2$ line (d) none of these

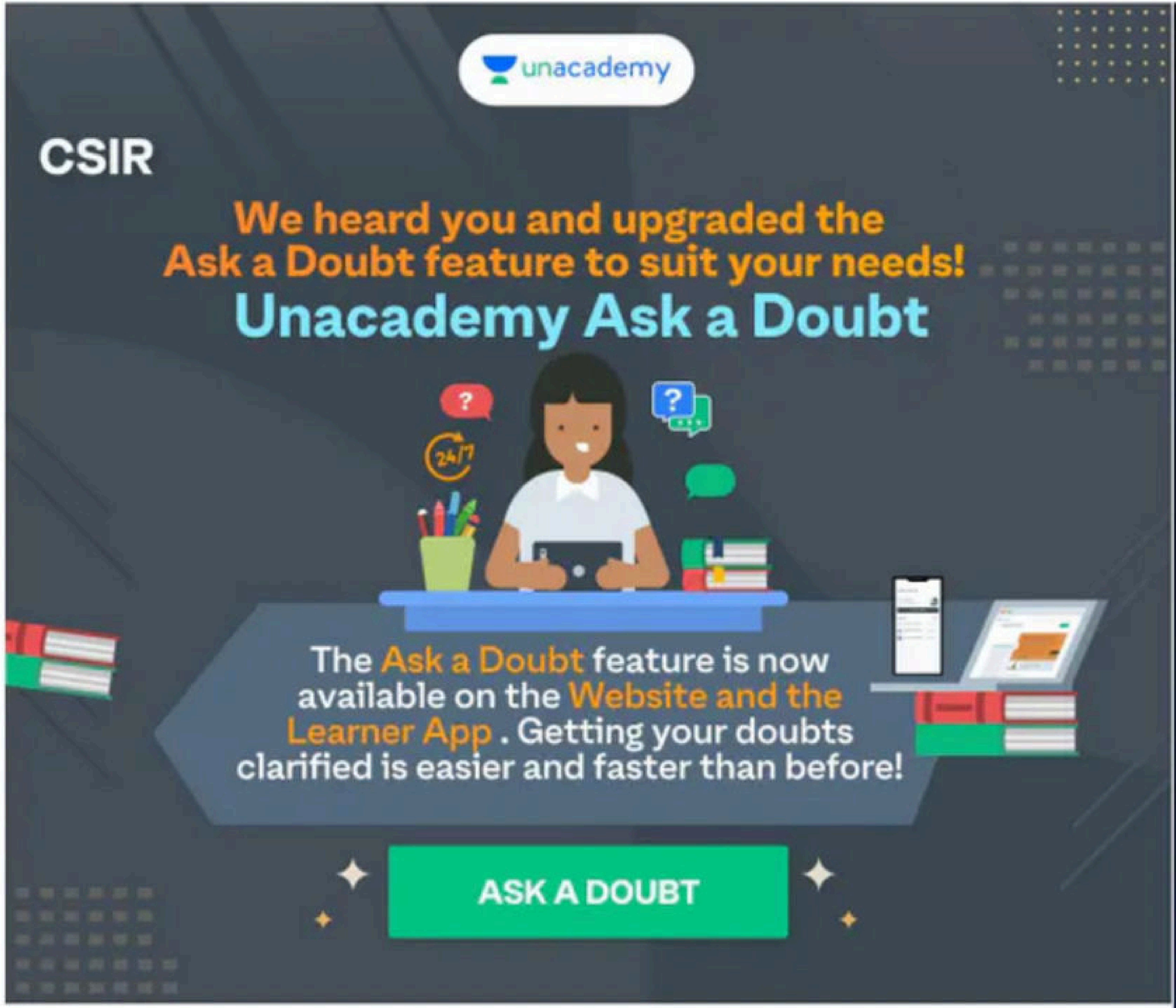
Q.3. The tangent at origin of the curve $2y^2 = x^2(2 - x)$ is

(a) $x = +2y$ and $x=-2y$

(b) $y = 2x$ and $y=-2x$

(c) $x = y$ and $x=-y$

(d) none of these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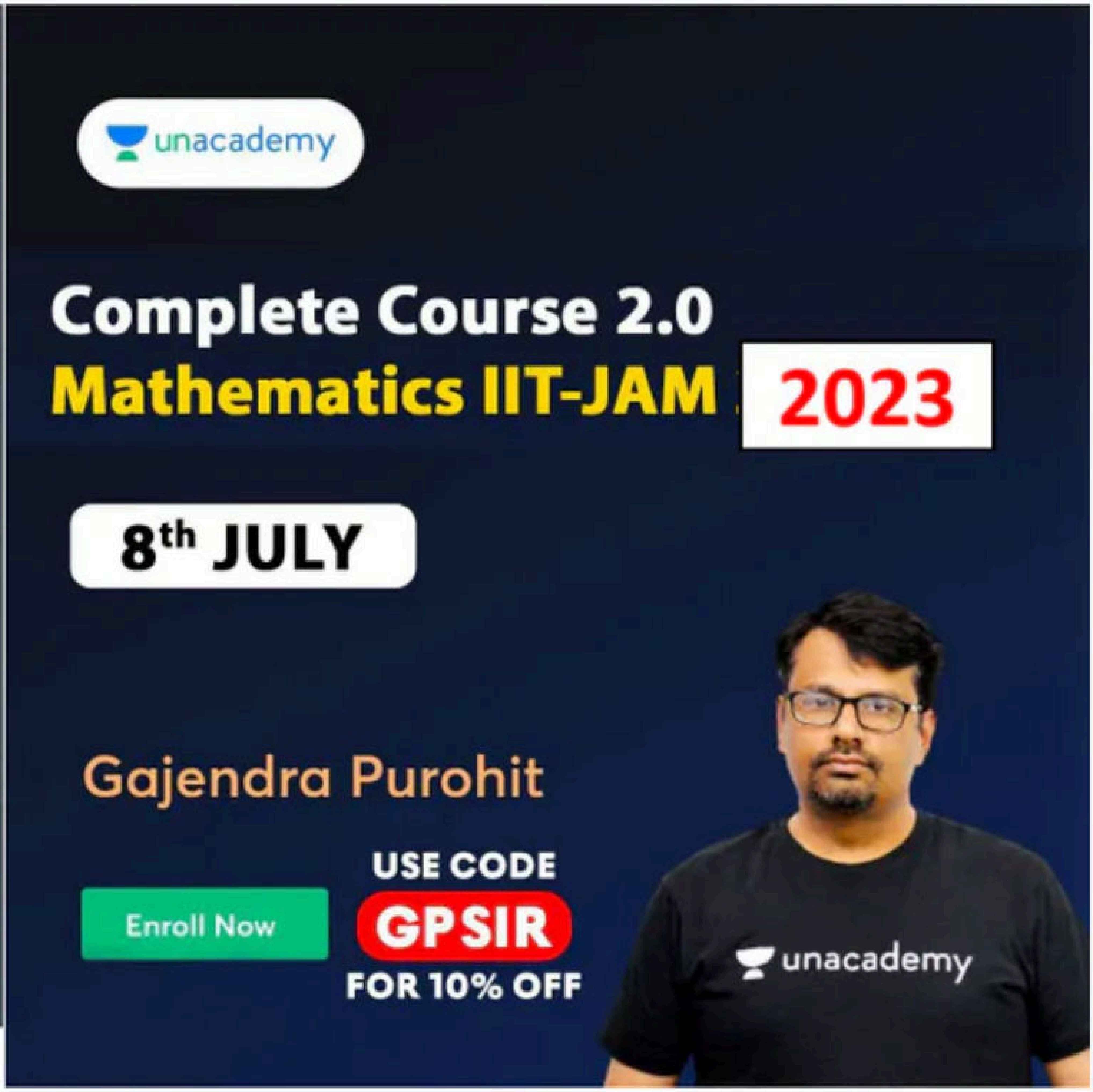
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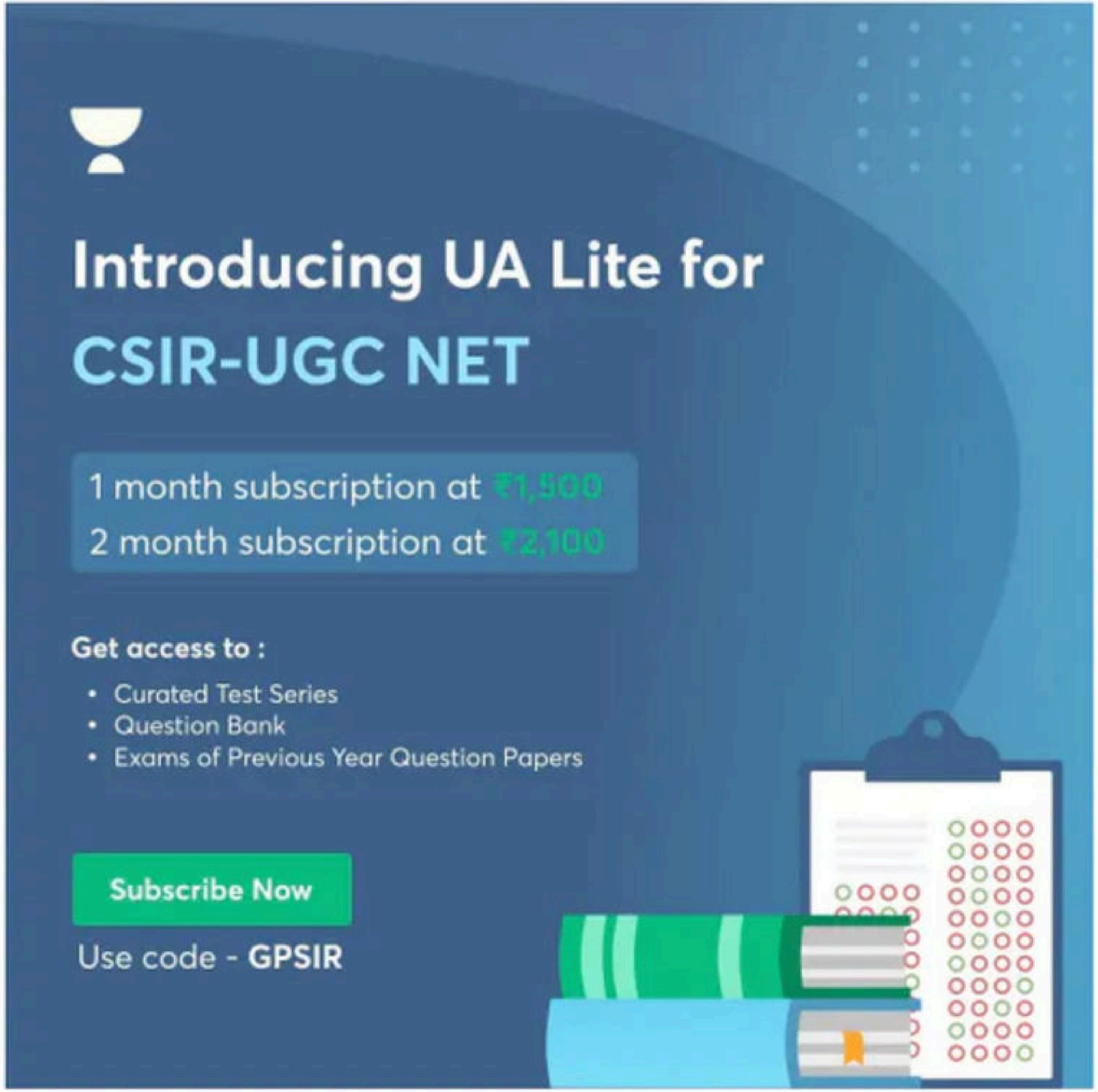
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