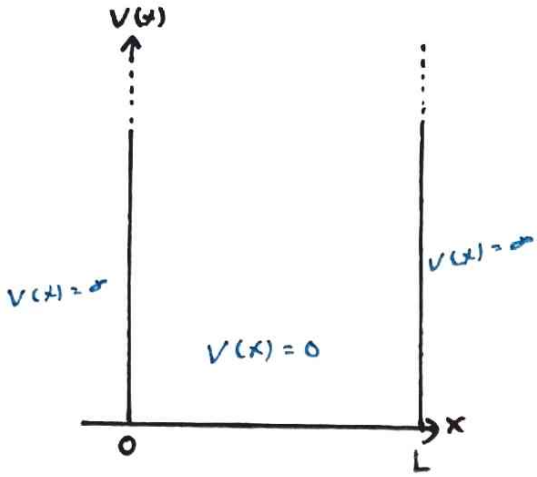
Sonsuz Kuyu



$$V(x) = \begin{cases} 0, & 0<x<L \\ \infty, & \text{diğer yerlerde} \end{cases}$$

$$H|\psi\rangle = E|\psi\rangle$$

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2} + \underbrace{V(x)}_{0}\right]|\psi\rangle = E|\psi\rangle$$

$$-\frac{\hbar^2}{2m}|\psi\rangle = E|\psi\rangle \Rightarrow \frac{d^2\psi}{dx^2} = -\frac{2mE}{\hbar^2}\psi$$

$$\Rightarrow \frac{d^2\psi}{dx^2} + k^2\psi = 0, \quad k = \sqrt{\frac{2mE}{\hbar^2}} = \frac{\sqrt{2mE}}{\hbar}, \quad E = \frac{\hbar^2k^2}{2m}$$

$\psi(x) = A\sin kx + B\cos kx$, Sınırlarda; $\psi(0) = \psi(L) = 0$ olmalı.

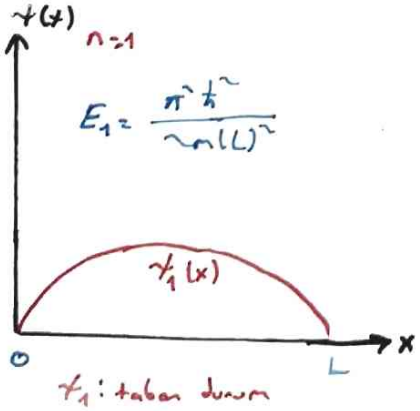
$$\psi(0) = A.\sin 0 + B\cos 0 = 0 \Rightarrow B = 0$$

$$\psi(L) = A\sin kL + 0\cos kL = 0 \Rightarrow A\sin kL = 0 \Rightarrow k_n = \frac{n\pi}{L}, \quad n = 1,2,3\cdots$$

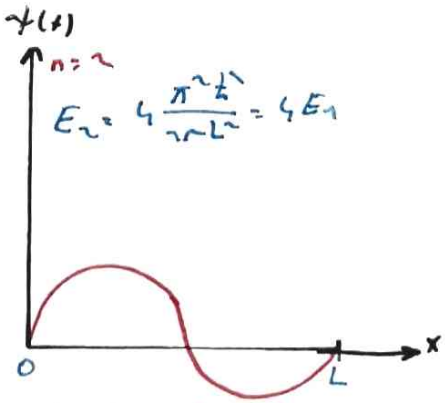
$$\Rightarrow \psi_n(x) = A\sin\left(\frac{n\pi}{L}x\right), \quad E_n = \frac{\hbar^2k_n^2}{2m} \Rightarrow E_n = \frac{\hbar^2n^2\pi^2}{2m(L)^2}$$

$$1 = \langle\psi|\psi\rangle = \int_0^a |A|^2\sin^2\left(\frac{n\pi}{L}x\right)dx \Rightarrow A = \sqrt{\frac{2}{L}}$$

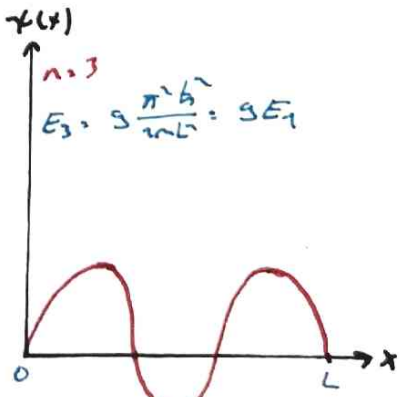
$$\Rightarrow \psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi}{L}x\right), \quad E_n = n^2\frac{\pi^2\hbar^2}{2m(L)^2}$$



ψ_1 : taban durum



ψ_2 : 1. uyarılmış durum



ψ_3 : 2. uyarılmış durum

1) L genişliğindeki bir sonsuz kuyu potansiyelinde bulunan bir parçacığın dalga fonksiyonu, ilk üç durağan durumun lineer kombinasyonu şeklinde aşağıdaki gibi verilmiştir:

$$\phi(x) = \frac{1}{\sqrt{2}}\psi_1 + \frac{1}{\sqrt{3}}\psi_2 + \frac{1}{\sqrt{6}}\psi_3$$

a) Parçacığın enerjisi ölçüldüğünde hangi değerler hangi olasılıklar ile elde edilir? $\phi(x,t)$'yi oluşturunuz.

b) Enerjinin beklenen değeri nedir?

a: $|\phi\rangle = \frac{1}{\sqrt{2}}|\psi_1\rangle + \frac{1}{\sqrt{3}}|\psi_2\rangle + \frac{1}{\sqrt{6}}|\psi_3\rangle$ $\quad E_n = \frac{\pi^2\hbar^2}{2mL^2}n^2$

$|\psi_1\rangle$ taban durum E_1, $|\psi_2\rangle$ 1. uyarılmış durum E_2, $|\psi_3\rangle$ 2. uyarılmış durum E_3

$E_1 = \frac{\pi^2\hbar^2}{2mL^2}$, $E_2 = \frac{4\pi^2\hbar^2}{2mL^2}$, $E_3 = \frac{9\pi^2\hbar^2}{2mL^2}$ enerjileri elde edilir.

Olasılıklar;

- $P(E_1) = |\langle\psi_1|\phi\rangle|^2 = \left|\frac{1}{\sqrt{2}}\underbrace{\langle\psi_1|\psi_1\rangle}_{\delta_{11}=1} + \frac{1}{\sqrt{3}}\underbrace{\langle\psi_1|\psi_2\rangle}_{\delta_{12}=0} + \frac{1}{\sqrt{6}}\underbrace{\langle\psi_1|\psi_3\rangle}_{\delta_{13}=0}\right|^2$

  $P(E_1) = \left|\frac{1}{\sqrt{2}}\right|^2 = \frac{1}{2}$ //

- $P(E_2) = |\langle\psi_2|\phi\rangle|^2 = \left|\frac{1}{\sqrt{2}}\underbrace{\langle\psi_2|\psi_1\rangle}_{\delta_{21}=0} + \frac{1}{\sqrt{3}}\underbrace{\langle\psi_2|\psi_2\rangle}_{\delta_{22}=1} + \frac{1}{\sqrt{6}}\underbrace{\langle\psi_2|\psi_3\rangle}_{\delta_{23}=0}\right|^2$

  $P(E_2) = \left|\frac{1}{\sqrt{3}}\right|^2 = \frac{1}{3}$ //

- $P(E_3) = |\langle\psi_3|\phi\rangle|^2 = \left|\frac{1}{\sqrt{2}}\underbrace{\langle\psi_3|\psi_1\rangle}_{\delta_{13}=0} + \frac{1}{\sqrt{3}}\underbrace{\langle\psi_3|\psi_2\rangle}_{\delta_{32}=0} + \frac{1}{\sqrt{6}}\underbrace{\langle\psi_3|\psi_3\rangle}_{\delta_{33}=1}\right|^2$

  $P(E_3) = \left|\frac{1}{\sqrt{6}}\right|^2 = \frac{1}{6}$ //

$P(E_1) + P(E_2) + P(E_3) = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = 1$ //

- $\psi_n(x,t) = \sum_{n=1}^{\infty} c_n \psi_n(x,0)\, e^{-i\frac{E_n}{\hbar}t}$

$$\phi(x,t=0) = \sqrt{\tfrac{1}{2}}\,\psi_1(x,0) + \sqrt{\tfrac{1}{3}}\,\psi_2(x,0) + \sqrt{\tfrac{1}{6}}\,\psi_3(x,0)$$

$$\phi(x,t) = \sqrt{\tfrac{1}{2}}\,\underbrace{\psi_1(x,0)\, e^{-iE_1t/\hbar}}_{\psi_1(x,t)} + \sqrt{\tfrac{1}{3}}\,\underbrace{\psi_2(x,0)\, e^{-iE_2t/\hbar}}_{\psi_2(x,t)} + \sqrt{\tfrac{1}{3}}\,\underbrace{\psi_3(x,0)\, e^{-iE_3t/\hbar}}_{\psi_3(x,t)}$$

b:

$$\langle E\rangle = \langle H\rangle = \sum_{n=1}^{\infty} |c_n|^2 E_n$$

$$\langle E\rangle = \sum_{n=1}^{3} \underbrace{|c_n|^2}_{P(E_n)} E_n = \sum_{n=1}^{3} P(E_n) E_n = P(E_1)E_1 + P(E_2)E_2 + P(E_3)E_3$$

$$\langle E\rangle = \frac{1}{2}\frac{\pi^2\hbar^2}{2mL^2} + \frac{1}{3}\frac{4\pi^2\hbar^2}{2mL^2} + \frac{1}{6}\,9\,\frac{\pi^2\hbar^2}{2mL^2} = \frac{\pi^2\hbar^2}{2mL^2}\left(\frac{1}{2} + \frac{4}{3} + \frac{3}{2}\right)$$

$$\langle E\rangle = \frac{\pi^2\hbar^2}{2mL^2}\left(\frac{20}{6}\right) \Rightarrow \langle E\rangle = \frac{5}{3}\frac{\pi^2\hbar^2}{mL^2} \;//$$

2) Sonsuz kuyu potansiyelinde bulunan bir parçacığın başlangıç ($t=0$) dalga fonksiyonu ilk iki kararlı durumun bir lineer kombinasyonu şeklinde verilmiştir:

$$\Psi(x,0) = A\left(\psi_1(x,0) + \psi_2(x,0)\right)$$

a) Ψ'yi normalleyiniz.

b) $\Psi(x,t)$ ve $|\Psi(x,t)|^2$'yi bulunuz. $|\Psi(x,t)|^2$'yi zamanın bir fonksiyonu olarak ifade ediniz.

c) $\langle x\rangle$'i hesaplayınız. Bunun zamanla salınım yaptığına dikkat ediniz ve bu salınımın açısal frekansını ve genliğini belirleyiniz.

d) Momentumun beklenen değerini hesaplayınız.

e) Bu parçacığın enerjisi ölçülürse hangi değerler hangi olasılıklarla elde edilir?

$$|\Psi(x,0)\rangle = A\,|\psi_1(x,0)\rangle + A\,|\psi_2(x,0)\rangle$$

$$\psi_1(x,t) = \sqrt{\frac{2}{L}}\sin\left(\frac{\pi x}{L}\right)e^{-iE_1 t/\hbar}, \quad E_1 = \frac{\pi^2\hbar^2}{2mL^2} \Rightarrow \psi_1(x,0) = \sqrt{\frac{2}{L}}\sin\left(\frac{\pi x}{L}\right)$$

$$\psi_2(x,t) = \sqrt{\frac{2}{L}}\sin\left(\frac{2\pi x}{L}\right)e^{-iE_2 t/\hbar}, \quad E_2 = 4\frac{\pi^2\hbar^2}{2mL^2} \Rightarrow \psi_2(x,0) = \sqrt{\frac{2}{L}}\sin\left(\frac{2\pi x}{L}\right)$$

a:
$$1 = \langle\Psi(x,0)|\Psi(x,0)\rangle = A^*\left[\langle\psi_1| + \langle\psi_2|\right]A\left[|\psi_1\rangle + |\psi_2\rangle\right]$$

$$\Rightarrow 1 = |A|^2\left[\underbrace{\langle\psi_1|\psi_1\rangle}_{\delta_{11}=1} + \underbrace{\langle\psi_1|\psi_2\rangle}_{\delta_{12}=0} + \underbrace{\langle\psi_2|\psi_1\rangle}_{\delta_{21}=0} + \underbrace{\langle\psi_2|\psi_2\rangle}_{\delta_{22}=1}\right] = 2A^2$$

$$\Rightarrow A = \frac{1}{\sqrt{2}}$$

b:
$$\Psi(x,0) = \frac{1}{\sqrt{2}}\psi_1(x,0) + \frac{1}{\sqrt{2}}\psi_2(x,0)$$

$$\Psi(x,t) = \frac{1}{\sqrt{2}}\psi_1(x,0)e^{-iE_1 t/\hbar} + \frac{1}{\sqrt{2}}\psi_2(x,0)e^{-iE_2 t/\hbar}$$

$$\cdot |\Psi(x,t)|^2 = \frac{1}{2}\left[\psi_1^* e^{+iE_1 t/\hbar} + \psi_2^* e^{+iE_2 t/\hbar}\right]\frac{1}{2}\left[\psi_1 e^{-iE_1 t/\hbar} + \psi_2 e^{-iE_2 t/\hbar}\right]$$

$$|\Psi(x,t)|^2 = \frac{1}{2}\Big[\underbrace{\psi_1^*\psi_1}_{|\psi_1|^2}\underbrace{e^{i(E_1-E_1)t/\hbar}}_{e^0} + \underbrace{\psi_2^*\psi_2}_{|\psi_2|^2}\underbrace{e^{i(E_2-E_2)t/\hbar}}_{e^0} + \psi_1^*\psi_2 e^{-i(E_2-E_1)t/\hbar} + \psi_2^*\psi_1 e^{-i(E_1-E_2)t/\hbar}\Big]$$

$\psi_1^*\psi_2 = \psi_2^*\psi_1$, $E_2 - E_1 = \Delta E \Rightarrow$

$$|\Psi(x,t)|^2 = \frac{1}{2}\left[|\psi_1|^2 + |\psi_2|^2 + \psi_1\psi_2\underbrace{\left(e^{-i\Delta E t/\hbar} + e^{+i\Delta E t/\hbar}\right)}_{2\cos(\Delta E \frac{t}{\hbar})}\right]$$

$$\frac{e^{i\alpha} + e^{-i\alpha}}{2} = \cos\alpha$$

$$|\Psi(x,t)|^2 = \frac{1}{2}\left[|\psi_1|^2 + |\psi_2|^2 + 2\psi_1\psi_2\cos\left(\frac{\Delta E}{\hbar}t\right)\right] \qquad \Delta E = E_2 - E_1 = (4-1)\frac{\pi^2\hbar^2}{2mL^2}$$

$$\Delta E = 3\frac{\pi^2\hbar^2}{2mL^2}$$

$$\frac{\Delta E}{\hbar} = 3\frac{\pi^2\hbar}{2mL^2}, \quad \omega = \frac{\pi^2\hbar}{2mL^2} \Rightarrow \frac{\Delta E}{\hbar} = 3\omega$$

$$|\Psi(x,t)|^2 = \frac{1}{2}\left[|\psi_1|^2 + |\psi_2|^2 + 2\psi_1\psi_2\cos 3\omega t\right]$$

$$|\Psi(x,t)|^2 = \frac{1}{2}\left[\frac{2}{L}\sin^2\left(\frac{\pi x}{L}\right) + \frac{2}{L}\sin^2\left(\frac{2\pi x}{L}\right) + \frac{4}{L}\sin\left(\frac{\pi x}{L}\right)\sin\left(\frac{2\pi x}{L}\right)\cos(3\omega t)\right]$$

$$|\Psi(x,t)|^2 = \frac{1}{L}\sin^2\left(\frac{\pi x}{L}\right) + \frac{1}{L}\sin^2\left(\frac{2\pi x}{L}\right) + \frac{2}{L}\sin\left(\frac{\pi x}{L}\right)\sin\left(\frac{2\pi x}{L}\right)\cos(3\omega t)$$

c:

$$\langle x\rangle = \langle\Psi(x,t)|\,x\,|\Psi(x,t)\rangle = \int_0^L \Psi^*(x,t)\,x\,\Psi(x,t)\,dx$$

$$\langle x\rangle = \frac{1}{L}\underbrace{\int_0^L x\sin\left(\frac{\pi x}{L}\right)dx}_{I_1} + \frac{1}{L}\underbrace{\int_0^L x\sin\left(\frac{2\pi x}{L}\right)dx}_{I_2} + \frac{2}{L}\underbrace{\int_0^L x\sin\left(\frac{\pi x}{L}\right)\sin\left(\frac{2\pi x}{L}\right)\cos(3\omega t)dx}_{I_3}$$

$$\cdot I_1 = \int_0^L x\sin^2\left(\frac{\pi x}{L}\right)dx = \int_0^L x\left(\frac{1}{2} - \cos\left(\frac{2\pi x}{L}\right)\right)dx = \int_0^L \frac{x}{2}dx - \int_0^L x\cos\left(\frac{2\pi x}{L}\right)dx$$

$$I_1 = \left(\frac{x^2}{4}\right)_0^L - \frac{1}{2}\int_0^L x\cos\left(\frac{2\pi x}{L}\right)dx = \frac{L^2}{4} - \frac{1}{2}\left[x\frac{L}{2\pi}\sin\left(\frac{2\pi x}{L}\right)\Big|_0^L - \int\frac{L}{2\pi}\sin\frac{2\pi x}{L}\,dx\right]$$

$\int u\,dv = uv - \int v\,du$

$u = x \rightarrow du = dx$

$dv = \cos\left(\frac{2\pi x}{L}\right)dx \rightarrow v = \frac{L}{2\pi}\sin\left(\frac{2\pi x}{L}\right)$

$$I_1 = \frac{L^2}{4} - \frac{1}{2}\left[\frac{L^2}{2\pi}\sin(2\pi) - 0\right] - \frac{1}{2}\frac{L}{2\pi}\frac{L}{2\pi}\cos\left(\frac{2\pi x}{L}\right)\Big|_0^L$$

$$I_1 = \frac{L^2}{4} - \frac{1}{2}\frac{L^2}{4\pi^2}\left(\cos 2\pi x\right)_0^L = \frac{L^2}{4} - \frac{L^2}{8\pi^2}\left(\cos(2\pi) - \cos(0)\right) = \frac{L^2}{4}$$

$1 \quad 1$

$1-1=0$

$$I_1 = \frac{L^2}{4}\ //$$

$$\cdot\ I_2 = \int_0^L x\sin\left(\frac{2\pi}{L}x\right)dx = \underbrace{\int_0^L \frac{x}{2}\,dx}_{L^2/4} - \frac{1}{2}\int_0^L x\cos\left(\frac{4\pi}{L}x\right)dx$$

$$I_2 = \frac{L^2}{4} - \frac{1}{2}\int_0^L x\cos\left(\frac{4\pi}{L}x\right)dx \qquad \int u\,dv = uv - \int v\,du$$

$u = x \rightarrow du = dx$

$dv = \cos\left(\frac{4\pi x}{L}\right)dx \rightarrow v = \frac{L}{4\pi}\sin\left(\frac{4\pi x}{L}\right)$

$$I_2 = \frac{L^2}{4} - \frac{1}{2}\left[x\frac{L}{4\pi}\sin\left(\frac{4\pi x}{L}\right)\Big|_0^L - \int_0^L\frac{L}{4\pi}\sin\left(\frac{4\pi x}{L}\right)dx\right]$$

$$I_2 = \frac{L^2}{4} - \frac{1}{2}\left[\frac{L^2}{4\pi}\sin(4\pi) - 0\right] - \frac{1}{2}\frac{L}{4\pi}\frac{L}{4\pi}\underbrace{\cos\left(\frac{4\pi x}{L}\right)\Big|_0^L}_{0}$$

$$I_2 = \frac{L^2}{4}\ //$$

$$I_3 = \int_0^L x \sin\left(\frac{\pi x}{L}\right) \sin\left(\frac{2\pi x}{L}\right) dx = \frac{1}{2}\int_0^L x\left(\cos\left(\frac{\pi x}{L}\right) - \cos\left(\frac{3\pi x}{L}\right)\right) dx$$

$$I_3 = \frac{1}{2}\int_0^L x\cos\left(\frac{\pi x}{L}\right) dx - \frac{1}{2}\int_0^L x\cos\left(\frac{3\pi x}{L}\right) dx$$

$$I_3 = \frac{1}{2}\left[\left(x\,\frac{L}{\pi}\sin\left(\frac{\pi x}{L}\right)\right)_0^L - \int_0^L \frac{L}{\pi}\sin\left(\frac{\pi x}{L}\right) dx\right] - \frac{1}{2}\left[x\,\frac{L}{3\pi}\sin\left(\frac{3\pi x}{L}\right) - \int_0^L \frac{L}{3\pi}\sin\left(\frac{3\pi x}{L}\right) dx\right]$$

$$I_3 = \frac{1}{2}\left[0 + \frac{L^2}{\pi^2}\cos\frac{\pi x}{L}\Big|_0^L\right] - \frac{1}{2}\left[0 + \frac{L^2}{9\pi^2}\cos\left(3\pi x\right)\Big|_0^L\right]$$

$-1-1=-2$ $\qquad$ $-1-1=-2$

$$I_3 = \frac{-L^2}{\pi^2} - \frac{1}{2}\left[\frac{L^2}{9\pi^2}(-2)\right] = -\frac{L^2}{\pi^2} + \frac{L^2}{9\pi^2} = -\frac{8L^2}{9\pi^2}$$

$$I_3 = -\frac{8L^2}{9\pi^2} \;//$$

$-\frac{8L^2}{9\pi^2}\cos 3\omega t$

$$\langle x\rangle = \frac{1}{2}I_1 + \frac{1}{2}I_2 + \frac{2}{2}I_3 \Rightarrow \langle x\rangle = \frac{1}{2}\frac{L^2}{4} + \frac{1}{2}\frac{L^2}{4} + \frac{2}{2}\left(-\frac{8L^2}{9\pi^2}\right)\cos 3\omega t$$

$$\langle x\rangle = \frac{L}{2}\left[1 - \frac{32}{9\pi^2}\cos(3\omega t)\right]$$

açısal frekans $\Rightarrow 3\omega = \frac{3\pi^2\hbar}{2mL^2}$ //

sonuç $\Rightarrow \frac{32}{9\pi^2}\left(\frac{L}{2}\right) = 0{,}36\left(\frac{a}{2}\right)$ //

d:

$$\langle p\rangle = m\frac{d}{dt}\langle x\rangle$$

$$\langle p\rangle = m\frac{d}{dt}\left[\frac{L}{2}\left(1 - \frac{32}{9\pi^2}\cos(3\omega t)\right)\right] = \frac{8\hbar}{3L}\sin(3\omega t) \;//$$

e: $P(E_1) = |\langle\psi_1|\Psi\rangle|^2 = \frac{1}{2}$ $\qquad$ $\langle E\rangle = \frac{1}{2}E_1 + \frac{1}{2}E_2 = \frac{5\pi^2\hbar^2}{4mL^2}$

$P(E_2) = |\langle\psi_2|\Psi\rangle|^2 = \frac{1}{2}$

3) Sonsuz kuyu potansiyelinde bulunan bir parçacığın dalga fonksiyonu

$$\psi(x,0) = A\,x(L-x), \quad (0<x<L)$$

olarak verilmiştir

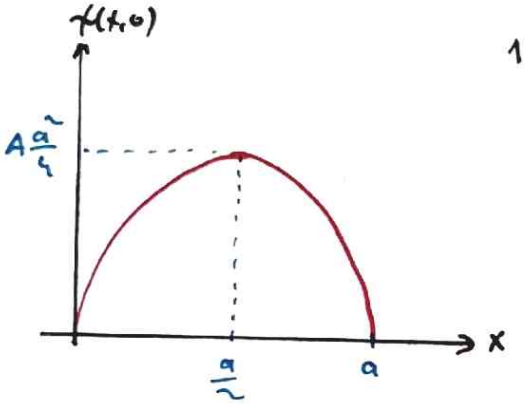
a) $\psi(x,0)$'ın grafiğini çiziniz ve A sabitini belirleyiniz.

b) $\psi(x,t)$'yi bulunuz.

c) Bir enerji ölçümünde E_1 bulunma olasılığı nedir?

d) Enerjinin beklenen değerini bulunuz.

a:



$$1 = \langle\psi|\psi\rangle = \int_0^a A^2 (x(L-x))^2 A\,(x(L-x))\,dx$$

$$1 = |A|^2 \int_0^a (x^3 - 2x^2L + L^2x^2)\,dx$$

$$1 = |A|^2 \left[\frac{x^4}{4} - \frac{2x^3L}{3} + \frac{L^2x^3}{3}\right]_0^L$$

$$A = \sqrt{\frac{30}{L^5}} \Rightarrow \psi(x,0) = \sqrt{\frac{30}{L^5}}\,x(L-x)$$

b:

$$\psi(x,t) = \sum_{n=1}^{\infty} c_n\,\psi_n(x,0)\,e^{-i\frac{E_n t}{\hbar}}$$

$$c_n = \langle\psi_n|\psi(x,0)\rangle = \int_0^a \underbrace{\sqrt{\frac{2}{L}}\sin\left(\frac{n\pi}{L}x\right)}_{\psi_n} \underbrace{\sqrt{\frac{30}{L^5}}\,x(L-x)}_{\psi}\,dx$$

$$c_n = \frac{2\sqrt{15}}{L^3}\left[L\int_0^L x\sin\left(\frac{n\pi}{L}x\right)dx - \int_0^L x^2\sin\left(\frac{n\pi}{L}x\right)dx\right]$$

$$c_n = \frac{2\sqrt{15}}{L^3}\left\{L\left[\left(\frac{L}{n\pi}\right)^2\sin\left(\frac{n\pi}{L}x\right) - \frac{xL}{n\pi}\cos\left(\frac{n\pi}{L}x\right)\right]_0^L - \left[2\left(\frac{L}{n\pi}\right)^2 x\sin\left(\frac{n\pi}{L}x\right) - \frac{\left(\frac{n\pi}{L}x\right)^2 - 2}{\left(\frac{n\pi}{L}\right)^3}\cos\left(\frac{n\pi}{L}x\right)\right]_0^L\right\}$$

$$c_n = \frac{2\sqrt{15}}{L^3}\left[-\frac{L^3}{n\pi}\cos(n\pi) + L^3\frac{(n\pi)^2-2}{(n\pi)^3}\cos(n\pi) + \frac{2a^3}{(n\pi)^3}\cos 0\right]$$

$$c_n = \frac{4\sqrt{15}}{(n\pi)^3}\left[\cos 0 - \cos n\pi\right] \Rightarrow c_n = \begin{cases} 0, & n \text{ çift} \\ \frac{8\sqrt{15}}{(n\pi)^3}, & n \text{ tek} \end{cases}$$

$$\Rightarrow \psi(x,t) = \sqrt{\frac{30}{L}}\left(\frac{2}{\pi}\right)^3 \sum_{n=1,3,5..} \frac{1}{n^3}\sin\left(\frac{\pi n}{L}x\right) e^{-i E_n t/\hbar} \quad //$$

c:
$$P(E_1) = |c_1|^2 = \left|\frac{8\sqrt{15}}{\pi^3}\right|^2 = 0{,}99855 \Rightarrow \%\,99$$

d:
$$\langle E\rangle = \langle H\rangle = \sum_{n=1,3,5} |c_n|^2 E_n = \frac{480\hbar^2}{\pi^4 mL^2}\sum_{n=1,3,5}\frac{1}{n^4} = \frac{5\hbar^2}{mL^2} \quad //$$

Ödev: Sonsuz kuyu potansiyelinde hareket eden bir parçacık;

$$\psi(x,0) = \begin{cases} Ax, & 0 \le x \le L/2 \\ A(L-x), & L/2 \le x \le L \end{cases}$$

ile verilen bir başlangıç dalga fonksiyonuna sahiptir.

a) $\psi(x,0)$'ın grafiğini çiziniz ve A sabitini belirleyiniz.

b) $\psi(x,t)$'yi bulunuz.

c) Bir enerji ölçümünde E_1 bulunma olasılığı nedir?

d) Enerjinin beklenen değerini bulunuz.