Massachusetts Institute of Technology
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**6.050J/2.110J** **Information and Entropy** **Spring 2003**

# Problem Set 9 Solutions

## Solution to Problem 1: Well, Well, Well

### Solution to Problem 1, part a.

Inside the well V(x) = 0 and therefore

$$i\hbar \frac{\partial \psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2 \psi(x,t)}{\partial x^2} \tag{9–6}$$

### Solution to Problem 1, part b.

If E has a nonzero imaginary part $E_{imag}$, then the magnitude of $f(t)$ is a function of time, in particular

$$\mid f(t) \mid = exp(E_{imag} t/\hbar) \tag{9–7}$$

If $E_{imag} > 0$ then $\mid f(t) \mid$ gets large for large values of $t$ (i.e., it blows up at infinity). If $E_{imag} < 0$ then $\mid f(t) \mid$ gets large for large values of $-t$ (i.e., it blows up at negative infinity). In either case it is impossible to normalize $\psi(x)$.

### Solution to Problem 1, part c.

$$E\phi(x) = -\frac{\hbar^2}{2m}\frac{\partial^2 \phi(x,t)}{\partial x^2} \tag{9–8}$$

### Solution to Problem 1, part d.

Since

$$\begin{aligned}
\phi(x) &= a\sin(kx) + b\cos(kx) && (9–9)\\
\frac{d\phi(x)}{dx} &= ak\cos(kx) - bk\sin(kx) && (9–10)\\
\frac{d^2\phi(x)}{dx^2} &= -ak^2\sin(kx) - bk^2\cos(kx) &&\\
&= -k^2\phi(x) && (9–11)
\end{aligned}$$

Therefore

$$E\phi(x) = \left(\frac{\hbar^2 k^2}{2m}\right)\phi(x) \tag{9–12}$$

so

$$E = \frac{\hbar^2 k^2}{2m} \tag{9–13}$$

## Solution to Problem 1, part e.

One of the boundary conditions is $\phi(0) = 0$, so

$$\begin{aligned} 0 &= \phi(0) \\ &= asin(0) + bcos(0) \\ &= b \end{aligned} \tag{9–14}$$

Since we know the wavefunction is nonzero, $a$ must be nonzero as well.

## Solution to Problem 1, part f.

$\phi(x)$ must be zero at the boundaries, which implies

$$\frac{k = j\pi}{L} \tag{9–15}$$

so that $\sin(-kL) = 0$.

## Solution to Problem 1, part g.

$$e_j = \frac{\hbar^2 \pi^2 j^2}{2mL^2} \tag{9–16}$$

## Solution to Problem 1, part h.

$$\phi_j(x) = a \sin\left(\frac{j\pi x}{L}\right) \tag{9–17}$$

## Solution to Problem 1, part i.

$$e_1 = \frac{\hbar^2 \pi^2}{2mL^2} \tag{9–18}$$

## Solution to Problem 1, part j.

$$e_2 = \frac{2\hbar^2 \pi^2}{mL^2} \tag{9–19}$$

## Solution to Problem 1, part k.

$$e_1 = \frac{\hbar^2 \pi^2}{2mL^2} \tag{9–20}$$

$$= \frac{(1.054 \times 10^{-34}\text{Joule-seconds})^2 \times (3.1416)^2}{2 \times (9.109 \times 10^{-31}\text{kilograms}) \times (2 \times 10^{-8}\text{meters})^2} \tag{9–21}$$

$$= 1.506 \times 10^{-22}\text{Joules} \tag{9–22}$$

$$\tag{9–23}$$

## Solution to Problem 1, part l.

Express this ground-state energy in electron-volts (1 eV$= 1.602 \times 10^{-19}$ Joules).

$$\begin{aligned} e_1 &= 1.506 \times 10^{-22}\text{Joules} \\ &= 9.391 \times 10^{-4}\text{eV} \end{aligned} \tag{9–24}$$