Select the option that is equal to $\Psi(x, \pi/\omega)$.

KEY for Q7

A $\mathrm{i}0.8\psi_1(x) + \mathrm{i}0.6\psi_2(x)$
B $-\mathrm{i}0.8\psi_1(x) - \mathrm{i}0.6\psi_2(x)$
C $\mathrm{i}0.8\psi_1(x) - \mathrm{i}0.6\psi_2(x)$
D $-\mathrm{i}0.8\psi_1(x) + \mathrm{i}0.6\psi_2(x)$
E $0.8\psi_1(x) + 0.6\psi_2(x)$
F $-0.8\psi_1(x) - 0.6\psi_2(x)$
G $0.8\psi_1(x) - 0.6\psi_2(x)$
H $-0.8\psi_1(x) + 0.6\psi_2(x)$

Q8 Consider a state of the harmonic oscillator with wave function given at all times t by

$$\Psi(x, t) = (A/\pi)^{1/4} \exp(-(Ax^2 + \mathrm{i}Bt)/2)$$

where A and B are positive real constants. Select the option that is equal to $m/\hbar$.

KEY for Q8

A $2A/B$
B $2B/A$
C A/B
D B/A
E $A/(2B)$
F $B/(2A)$
G $A/(\sqrt{2}B)$
H $B/(\sqrt{2}A)$

Q9 and Q10 share the same key and concern the following operators:

$\hat{\mathrm{p}}_x \equiv -\mathrm{i}\hbar d/dx$ $\quad$ $\hat{\mathrm{I}} \equiv (x\hat{\mathrm{p}}_x - \hat{\mathrm{p}}_x x)/\hbar$
$\hat{\mathrm{H}}_0 \equiv \hat{\mathrm{p}}_x^2/2m$ $\quad$ $\hat{\mathrm{J}} \equiv \hat{\mathrm{I}}\hat{\mathrm{p}}_x$
$\hat{\mathrm{V}} \equiv \frac{1}{2}m\omega^2 x^2$ $\quad$ $\hat{\mathrm{K}} \equiv \hat{\mathrm{p}}_x\hat{\mathrm{I}}$
$\hat{\mathrm{H}} \equiv \hat{\mathrm{H}}_0 + \hat{\mathrm{V}}$ $\quad$ $\hat{\mathrm{L}} \equiv \hat{\mathrm{I}}^2$

Q9 Select the *three* operators that commute with x.

Q10 Select the *two* operators that do *not* commute with $\hat{\mathrm{p}}_x$.

KEY for Q9 and Q10

A $\hat{\mathrm{p}}_x$
B $\hat{\mathrm{H}}_0$
C $\hat{\mathrm{V}}$
D $\hat{\mathrm{H}}$
E $\hat{\mathrm{I}}$
F $\hat{\mathrm{J}}$
G $\hat{\mathrm{K}}$
H $\hat{\mathrm{L}}$

Q11 to Q17 mainly concern Unit 6.

Q11 to Q17 concern the scattering of a beam of particles of mass m and closely defined energy $25\hbar^2/32mL^2$ by a one-dimensional finite square well of width $2L$. The potential energy function is given by

$$V(x) = \begin{cases} 0 & \text{for } |x| \leqslant L \\ 9\hbar^2/32mL^2 & \text{for } |x| > L. \end{cases}$$

The space-dependent part of the wave function is

$\psi(x) = A_1 \exp(\mathrm{i}k_\mathrm{A}x) + A_2 \exp(-\mathrm{i}k_\mathrm{A}x)$ $\quad$ for $x < -L$
$\psi(x) = B_1 \exp(\mathrm{i}k_\mathrm{B}x) + B_2 \exp(-\mathrm{i}k_\mathrm{B}x)$ $\quad$ for $|x| \leqslant L$
$\psi(x) = C_1 \exp(\mathrm{i}k_\mathrm{C}x) + C_2 \exp(-\mathrm{i}k_\mathrm{C}x)$ $\quad$ for $x > L$

where $k_\mathrm{A}, k_\mathrm{B}$ and k_C are positive real constants.

Q11 to Q13 share the same key and concern wave numbers.

Q11 Select the option that is equal to k_A.

Q12 Select the option that is equal to k_B.

Q13 Select the option that is equal to k_C.

KEY for Q11 to Q13

A $1/L$
B $2/L$
C $3/4L$
D $5/4L$
E π/L
F $2\pi/L$
G $3\pi/2L$
H $5\pi/2L$

Q14 to Q17 concern the general case when B_1 and B_2 are arbitrary complex constants.

Q14 Select from the key the *two* options that are equal to $(B_1 - B_2)$.

KEY for Q14

A $\mathrm{i}(A_1 + A_2)$
B $\mathrm{i}(A_1 - A_2)$
C $-\mathrm{i}(A_1 + A_2)$
D $-\mathrm{i}(A_1 - A_2)$
E $\mathrm{i}(C_1 + C_2)$
F $\mathrm{i}(C_1 - C_2)$
G $-\mathrm{i}(C_1 + C_2)$
H $-\mathrm{i}(C_1 - C_2)$

Q15 Select from the key the *two* options that are equal to $(B_1 + B_2)$.

KEY for Q15

A $\frac{4}{5}\mathrm{i}(A_1 + A_2)$
B $\frac{4}{5}\mathrm{i}(A_1 - A_2)$
C $-\frac{4}{5}\mathrm{i}(A_1 + A_2)$
D $-\frac{4}{5}\mathrm{i}(A_1 - A_2)$
E $\frac{4}{5}\mathrm{i}(C_1 + C_2)$
F $\frac{4}{5}\mathrm{i}(C_1 - C_2)$
G $-\frac{4}{5}\mathrm{i}(C_1 + C_2)$
H $-\frac{4}{5}\mathrm{i}(C_1 - C_2)$

Q16 and Q17 share the same key and concern probability currents.

Q16 Which, if any, of the options A–F is equal to the total probability current for $|x| \leqslant L$?

Q17 Which, if any, of the options A–F is equal to the total probability current for $|x| > L$?

KEY for Q16 and Q17

A $(\hbar k_\mathrm{B}/m)(|B_1|^2 + |B_2|^2)$
B $(\hbar k_\mathrm{B}/m)(|B_1|^2 - |B_2|^2)$
C $(\hbar k_\mathrm{B}/m)|B_1 + B_2|^2$
D $(\hbar k_\mathrm{B}/m)|B_1 - B_2|^2$
E $(\hbar k_\mathrm{B}/m)(B_1 + B_2)(B_1^* - B_2^*)$
F $(\hbar k_\mathrm{B}/m)(B_1 - B_2)(B_1^* + B_2^*)$
G None of the options A–F

Q18 to Q21 mainly concern Unit 8.

Q18 and Q19 concern the proton, whose gyromagnetic ratio is $2.67 \times 10^8\,\mathrm{s^{-1}\,T^{-1}}$.