What you should know about ...

Waves

1. Basic wave properties [Q1]
   - Superposition principle holds if wave equation is *linear*
   - $f = \omega/2\pi$, $\lambda = 2\pi/k$, wave speed $v = f\lambda = \omega/k$
   - What does wave velocity depend on? e.g., string: tension and mass per unit length
   - What is resonance?
   - Finding normal modes (as in homework): boundary conditions, counting wavelengths
   - Fourier series: a periodic function can be *uniquely* decomposed into a sum of sines and cosines
2. Interference phenomena [Q2,Q4]
   - Diffraction through or around object (slit, eyeball, etc.) with size a
     - total diffraction if $\lambda > a$; no diffraction if $\lambda \ll a$
     - Construction using path difference to derive $\sin\theta = \lambda/a$ formula for first minimum.
     - When can objects be resolved? (qualitative and quantitative)
   - Applying two-slit interference formula
     - Construction using path difference to derive formula for "bright spots": $d\sin\theta = n\lambda$
   - When is the small-angle approximation ($\sin\theta \approx \tan\theta \approx \theta$) valid?

What you should know about ...

Particlelike Properties of Waves and Wavelike Properties of Particles

1. Photon model [Q3]
   - photon energy/momentum related to frequency and wavelength
   - Basic relations for photons: $E = hf = hc/\lambda$; $E = pc$
   - Basic photon calculations (photons per second emitted, absorbed, visible photon wavelengths, etc.)
2. Photoelectric effect [Q3]
   - predictions of wave vs. particle models [also Q5,Q6]
   - analysis of experiment: $K = hf - W = hc/\lambda - W$
   - What is a work function?
3. de Broglie wavelength: what does it mean? [Q4,Q5]
   - $p = h/\lambda$ and $E = hf$ ($E \neq hc/\lambda$ for massive particles!). Nonrelativistic free particle: $E = p^2/2m$
   - relationship between kinetic energy and wavelength (qualitative and quantitative)
     - nonrelativistic: $\lambda = h/\sqrt{2Km} = hc/\sqrt{2Kmc^2}$. Relativistic version: $\lambda = hc/\sqrt{K(K+2mc^2)}$
   - diffraction and interference of particles
     - occurs when deBroglie λ comparable to slit size or other relevant size.
     - applications: electron interference experiments, resolving particles ($\lambda \lesssim a$)

What you should know about ...

Quantum Mechanics

1. Probability interpretation of wave function [Q6]
   - Calculating the probability to find a particle in some region of space (given a wave function)
   - Possible results of successive measurements of an observable (e.g., energy or position); "collapse"
2. The probability rule and application to spin wave functions [Q6]
   - If you have quanta in a state $|\psi\rangle$ and measure an observable O of the quanta which has possible eigenvalues O_n, $n = 1, 2, 3, \ldots$, then the probability that your measurement yields the specific value O_n for the observable is

     $$Pr(O_n) = |\langle O_n|\psi\rangle|^2,$$

     with $|O_n\rangle$ being the eigenstate of the observable O with eigenvalue O_n.
3. Time Dependence of a stationary state [$\propto e^{-iE_n t/\hbar}$] [Q6]
   - When is a solution a "stationary state"? [Definite energy $\Longrightarrow$ energy eigenfunctions!]
   - What happens if you combine two stationary states?
4. Quanton in a Box [Q7]
   - derivation of energy eigenvalues $E_n = h^2n^2/8mL^2$ and eigenfunctions $\psi_E(x) = A\,\sin(n\pi x/L)$ in box
5. Bohr model assumptions $\Longrightarrow$ energy levels $E_n = -ke^2/2a_0n^2$ and radii $r_n = n^2a_0$ in hydrogen [Q7]
   - Bohr radius $a_0 = h^2/4\pi^2mke^2 \approx 0.053\,\text{nm} \Longrightarrow E_n = -(13.6\,\text{eV})/n^2$. Results for hydrogen-like atoms.
6. Photon spectral lines [Q8]
   - Relationship to energy levels (differences!)
   - Infinite well vs. oscillator vs. hydrogen atom (energy levels *and* spectra)
   - Pauli exclusion principle and spin; fermions vs. bosons
7. Atoms [Q9]: Selection rules (e.g., $\Delta l = \pm 1$), predicting ground state configuration, periodic table of elements

What you should know about ...

Energy Eigenfunctions [Q10, Q11]

1. Schrödinger eq: $-\frac{\hbar^2}{2m}\frac{d^2\psi_E(x)}{dx^2} + V(x)\psi_E(x) = E\psi_E(x)$. Is a given function a possible energy eigenfunction?
2. $\psi_E(x)$ is wavelike (curving towards the axis) in a classically allowed region ($V(x) < E$)
3. The local *curvature* (2nd derivative!) is related to the local wavelength which is related to the local kinetic energy $K(x) = E - V(x)$ (see equations on previous page and $K = h^2/2m\lambda^2$).
4. $\psi_E(x)$ is exponential-like (curving away from the axis) in a classically forbidden region ($V(x) > E$)
5. The wavefunction must decay to zero at $|x| \to \infty$ (normalizability!).
6. This causes quantization of energy: Only for specific values of E does the wavefunction curve in the classically forbidden region in exactly the way needed for the wavefunction to approach zero at $|x| \to \infty$.
7. The quanta spend more time in regions where they move slowly (small $K(x)$) – wave function has larger amplitude there.
8. Tunneling: the ability of a wavefunction to leak through a finite barrier due to its exponential tail in the classically forbidden region.