The exam will focus on the **harmonic oscillator** and **rigid rotor**. You may bring a **hand-written** sheet (8½ by 11 inch) to the exam, containing whatever you want on one side of this sheet – you must hand this sheet in at the end of the exam. Note that tables of standard integrals, Legendre functions, spherical harmonics, physical constants, unit conversions etc. will be provided on a data sheet like the one posted on the web site (at [http://ux1.eiu.edu/~sapeebles/Data_sheet.pdf](http://ux1.eiu.edu/~sapeebles/Data_sheet.pdf)).

1. Learn the expressions for the energy levels of the harmonic oscillator (equation 5-33) and rigid rotor (equation 6-61) – these are easily remembered important expressions and can provide useful insight into the way the quantization in these systems is imposed.
2. You should be able to generate the Hamiltonian operator from classical energy expressions for the above systems and understand how to solve the Schrödinger equation to obtain expressions for the system energy for each of these cases. Know the definitions of such parameters as the force constant, rotational constant, reduced mass etc. (see for example, Example 5-3).
3. Make sure you are able to convert transition energies and frequencies between common units such as J, Hz and cm⁻¹.
4. Know the general form of the wavefunctions for the harmonic oscillator and rigid rotor – be able to construct them given the appropriate tables of Hermite polynomials (HO), Legendre polynomials (RR) etc. The harmonic oscillator wavefunction is given in equation (5-41) and the rigid rotor wavefunctions by the spherical harmonic functions (Table 6-3).
5. Know the definition of the parameter \( \alpha \) which appears in the HO wavefunctions (defined in equation (5-42)).
6. Know what the physical forms of the harmonic oscillator wavefunctions and the probability plots look like.
7. Be able to do problems of the sort that we did on the homework assignment – calculation of expectation values of \( x, x^2 \) and so on. Be able to do problems such as those shown in Examples 5-8, 5-9. The more you practice these problems, the easier it will be to spot the form of the standard integral that you are working towards for the final solution.
8. Note that the classical harmonic oscillator has a fixed amplitude, but a quantum mechanical one does not (page 174). It is possible to calculate a quantity known as the root mean-square displacement of a quantum mechanical oscillator (by taking the square root of the expectation value of \( x^2 \) (i.e. \( \langle x^2 \rangle^{1/2} \)) as a measure of the square of this amplitude.
9. Be able to manipulate the wavefunctions for the rigid rotor and harmonic oscillator) – i.e. calculation of normalization constants, be able to prove they’re orthonormal (Examples 5-4, 5-7, 6-4) know how to calculate expectation values etc. (as already discussed above).
10. We introduced the spherical harmonics (Table 6-3) during the treatment of the rigid rotor – these will be of critical importance in the treatment of the hydrogen atom as well. Make sure you are confident in constructing and using these functions.
11. Be able to construct the rigid rotor wavefunctions (which are the spherical harmonics – Table 6-3) from the appropriate tables of functions (associated Legendre functions – Table 6-2).
12. Know how to calculate what the rotational spectrum of a diatomic looks like (shown in Figure 6-6). Note that the quantum number \( J \) is often used in place of the quantum number \( l \) to designate rotational angular momentum quantum number – you should be familiar with both.
13. Be able to calculate bond lengths and rotational transition frequencies for a diatomic species (Example 6-5).
14. Equations (6-79) and (6-87) are of special significance and will turn up numerous times. Make sure you understand the significance of these equations.
15. The Cartesian and spherical polar forms of the angular momentum operators (equations (6-84) and (6-85) are particularly useful. You don’t need to remember these but be able to use them. Note that the polar form of the \( \hat{L}_z \) form is particularly easy to apply and so turns up often in quantum mechanical problems!
16. Understand the discussion on page 220 about the operators \( \hat{L}_x, \hat{L}_y, \hat{L}_z, \hat{L}^2 \) and whether they commute or not. This has important consequences on measurements of angular momentum.
17. Be sure that you understand the use of spherical polar coordinates and the use of the volume element \( d\tau = r^2\, dr \, \sin\theta \, d\theta \, d\phi \) in our integrals. For the rigid rotor problem this means that we integrate using the volume element \( (\sin\theta \, d\theta \, d\phi) \) – see page 215 and 216. We’ll discuss this more in relation to the H atom problem.