Physics 215 – Elementary Modern Physics

Equations for Final Exam

The following new equations you should have memorized, and understand how to use them:

Atomic Mass, Charge, Neutron Number: \( Q = Ze \quad A = Z + N \)

Approximate mass of an atom: \( M = A \text{ u} \)

Avogadro’s number: \( N_A = \frac{1 \text{ g}}{1 \text{ u}} \)

Radioactivity: \( R = \lambda N, \quad N = N_0 e^{-\lambda t}, \quad R = R_0 e^{-\lambda t}, \quad \lambda = \frac{\ln 2}{t_{1/2}}. \)

Stefan-Boltzmann law: \( \mathcal{F} = \sigma T^4 \)  

Ideal gas pressure: \( P = k_B n T \)

Types of Radioactive decay: Memorize this table

<table>
<thead>
<tr>
<th>Type</th>
<th>( \Delta Z )</th>
<th>( \Delta A )</th>
<th>( Q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>-2</td>
<td>-4</td>
<td>( (M_p - M_D - M_{\text{He}}) c^2 )</td>
</tr>
<tr>
<td>( \beta )</td>
<td>+1</td>
<td>0</td>
<td>( (M_p - M_D) c^2 )</td>
</tr>
<tr>
<td>e. c.</td>
<td>-1</td>
<td>0</td>
<td>( (M_p - M_D) c^2 )</td>
</tr>
<tr>
<td>( \beta^+ )</td>
<td>-1</td>
<td>0</td>
<td>( (M_p - M_D - 2m_e) c^2 )</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0</td>
<td>0</td>
<td>( (M_p - M_D) c^2 )</td>
</tr>
</tbody>
</table>

Stars things to know

- What are each of the following stars composed of: pre-main sequence star, main sequence star, white dwarf, and neutron star
- Which of these stars is undergoing fusion? What is the fuel being used up, and what is the final product?
- What type of pressure supports each of these stars from collapse?
- How to figure out the total Luminosity of a star from the radius and surface temperature (assuming it is a black body)
- OBAFGKM
- A general idea of how main sequence stars vary (radius, temperature, luminosity) based on their mass
- A general idea of the mass and size of a typical white dwarf or neutron star
- How to calculate the energy produced in simple nuclear fusions (no beta decay or electron capture)
The following review equations you should also memorize:

Speed of light: \( c = 3 \times 10^8 \, \text{m/s} \)

Lorentz factor: \( \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \)

Time dilation: \( \Delta t = \gamma \Delta \tau \)  
Length contraction: \( L = L_0/\gamma \)

Energy: \( E = \gamma mc^2 \), \( \gamma = \frac{1}{\sqrt{1 - u^2/c^2}} \)

Math with complex numbers: \( i^2 = -1 \), \( e^{i\theta} = \cos \theta + i \sin \theta \)  
\( (x + iy)^* = x - iy \)

Basic waves: \( \cos(kx - \omega t) \) or \( \sin(kx - \omega t) \) or \( e^{(ikx - \omega t)} \)

Wave relationships: \( \lambda = \frac{2\pi}{k} \), \( \frac{\omega}{2\pi} = f = \frac{1}{T} \)

For light waves: \( c = \lambda f \)

Quantum waves: \( E = hf = \hbar\omega \), \( p = \frac{h}{\lambda} = \hbar k \)

Planck’s constants: \( \hbar = h/2\pi \)

Size of atoms and nuclei: \( a = 10^{-10} \, \text{m} \), \( R = 10^{-15} \, \text{m} \)

Uncertainty relations: \( \Delta x \Delta p \geq \frac{\hbar}{2} \)

Momentum operator in 1D: \( p = \frac{\hbar}{i} \frac{\partial}{\partial x} \)  
in 3D: \( p_x = \frac{\hbar}{i} \frac{\partial}{\partial x} \), \( p_y = \frac{\hbar}{i} \frac{\partial}{\partial y} \), \( p_z = \frac{\hbar}{i} \frac{\partial}{\partial z} \)

Schrödinger’s Equation in 1D: \( i\hbar \frac{\partial}{\partial t} \Psi(x,t) = -\frac{\hbar^2}{2m} \frac{\partial^2}{\partial x^2} \Psi(x,t) + V(x,t) \Psi(x,t) \)

\( E\psi(x) = -\frac{\hbar^2}{2m} \frac{\partial^2}{\partial x^2} \psi(x) + V(x)\psi(x) \)

Probability of finding a particle in a range: \( P(a < x < b) = \int_a^b |\psi(x)|^2 \, dx \)
Angular momentum values: $L^2 = \hbar^2 \left( l^2 + l \right)$, $L_z = \hbar m$

Spin values: $s = \frac{1}{2}$, $S^2 = \hbar^2 \left( s^2 + s \right) = \frac{3}{4} \hbar^2$, $S_z = \hbar m_s$

Restrictions on quantum numbers: $n = 1, 2, 3, \ldots$, $l = 0, 1, 2, 3, \ldots, n - 1$, $m = -l, -l + 1, \ldots, 0, \ldots, l$, $m_s = \pm \frac{1}{2}$

The following new equations you need not memorize, but you should know how to use them if given to you:

Basic Masses: $u = 931.494 \text{ MeV} / c^2 = 1.661 \times 10^{-27} \text{ kg}$, $N_d = 6.022 \times 10^{23}$

Nuclear Decay: $2m_ec^2 = 1.02200 \text{ MeV}$, $M_{He} = 4.002602 \text{ u}$

Range of forces: $d = \frac{\hbar c}{m c^2}$

Planck’s Constants: $\hbar = 6.626 \times 10^{-34} \text{ J} \cdot \text{s} = 4.136 \times 10^{-15} \text{ eV} \cdot \text{s}$, $\hbar = 1.055 \times 10^{-34} \text{ J} \cdot \text{s} = 6.582 \times 10^{-16} \text{ eV} \cdot \text{s}$

Radiation and Degeneracy pressures: $P_r = \frac{\pi^2 \left( k_B T \right)^4}{45 \left( \hbar c \right)^3}$, $P_d = \frac{\hbar^2}{5 m \left( 3 \pi^2 \right)^{2/3}} \frac{1}{n^{5/3}}$

Newton’s Constant: $G = 6.673 \times 10^{-11} \text{ m}^3 / \text{kg} / \text{s}^2$

Gravitational time dilation: $\tau = t \sqrt{1 - \frac{2GM}{c^2 r}}$

Gravitational Red-shift: $\lambda = \lambda_0 \left( 1 - \frac{2GM}{c^2 r} \right)^{-1/2}$

Schwarzschild radius of a black hole: $R_s = \frac{2GM}{c^2}$

In addition to these equations, any equation that appeared on a previous exam may be tested on this exam. But if it isn’t listed here, you don’t need to memorize it.
Layout of the exam: Below is an outline of the exam

This test consists of five parts. Please note that in parts II through V, you can skip one question of those offered.

Part I: Multiple Choice (mixed new and review questions) [50 points]
For each question, choose the best answer (2 points each)

[questions 1-25]

Part II: Short answer (review material) [20 points]
Choose two of the following three questions and give a short answer (1-3 sentences) (10 points each).

[questions 26-28]

Part III: Short answer (new material) [30 points]
Choose three of the following four questions and give a short answer (1-3 sentences) (10 points each).

[questions 29-32]

Part IV: Calculation (review material) [40 points]
Choose two of the following three questions and perform the indicated calculations (20 points each)

[questions 33-35]

Part V: Calculation (new material): [60 points]
Choose three of the following four questions and perform the indicated calculations (20 points each)

[questions 36-39]

Exam information
- The exam will be in the usual room where we meet
- Wednesday, December 14, at 2:00 PM
- There will be 2 hours and 40 minutes for the final
  - 4 hours if you are granted extra time