Spring 2025 Physics Qualifying Exam
for Advancement to Candidacy
Part 1
May 9, 2025
9:00-11:15 PDT

If you are in the PhD in astronomy or PhD in medical physics programs, stop! This is the physics version of the exam. Please ask the proctor for the version appropriate for your program instead.

Do not write your name on your exam papers. Instead, write your student number on each page. This will allow us to grade the exams anonymously. We'll match your name with your student number after we finish grading.

This portion of the exam has 4 questions. Answer *any three* of the four. Do not submit answers to more than 3 questions—if you do, only the first 3 of the questions you attempt will be graded. If you attempt a question and then decide you don't want to it count, clearly cross it out and write "don't grade".

You have 2 hours and 15 minutes to complete 3 questions.

You are allowed to use one 8.5″ × 11″ formula sheet (both sides), and a handheld, non-graphing calculator.

Here is a possibly useful table of physical constants and formulas (see back of page as well):

absolute zero	0 K	-273°C
atomic mass unit	1 amu	1.661×10^{-27} kg
Avogadro's constant	N_A	6.02×10^{23}
Bohr radius of hydrogen atom	a_0	5.3×10^{-11} m
Boltzmann's constant	k_B	1.38×10^{-23} J/K
charge of an electron	e	1.6×10^{-19} C
distance from earth to sun	1 AU	1.5×10^{11} m
Laplacian in spherical coordinates	$\nabla^2\psi =$	$\frac{1}{r}\frac{\partial^2}{\partial r^2}(r\psi) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial\psi}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2\psi}{\partial\phi^2}$
mass of an electron	m_e	0.5110 MeV/c^2
mass of a neutron	m_n	1.67493×10^{-27} kg = 939.5654 MeV/c^2
mass of a proton	m_p	1.67262×10^{-27} kg = 938.2721 MeV/c^2
mass of the sun	M_{sun}	2×10^{30} kg
molecular weight of C		12
molecular weight of He		4
Newton's gravitational constant	G	6.7×10^{-11} N m^2 kg^{-2}
permittivity of free space	ϵ_0	8.9×10^{-12} C^2 N^{-1}/m^2
permeability of free space	μ_0	$4\pi \times 10^{-7}$ N/A^2
Planck's constant	h	6.6×10^{-34} J·s
radius of the Earth	R_{earth}	6.4×10^6 m
radius of a neutron	$R_{neutron}$	3×10^{-16} m
speed of light	c	3.0×10^8 m/s
Stefan-Boltzmann constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
Stirling's approximation	$N!$	$e^{-N}N^N\sqrt{2\pi N}$

1. A cubic vessel with a volume of 1 m^3 contains a uniform isotropic gas *out of thermal equilibrium* containing one mole of helium atoms. By some means every atom has a speed of exactly 200 m/s at time $t = 0$. The atoms collide elastically against the walls of the vessel, transferring no energy to them, and the system is isolated, allowing no energy transfer in or out. The system is allowed to reach thermal equilibrium.

A. Calculate the temperature of the gas in equilibrium.

B. Do an order of magnitude calculation of the time constant over which the system approaches local thermal equilbrium.

C. The system is slowly heated until the most common particle velocity is $0.5c$, where c is the speed of light. What is the temperature of the gas at this point? (Note: this part requires a relativistic treatment!)

2. A spinless point particle of mass m is placed in a 3D central potential of the form $V(r) = (1/2)kr^2$.

A. How many quantum states exist for which the particle's energy falls in the range $(E, E + \delta E)$?

B. Now the particle is replaced by a spherically symmetric object with mass m and moment of inertia I. How many quantum states exist for which the object's rotational kinetic energy falls in the range $(E, E + \delta E)$?

C. How many quantum states exist for which the object's total energy (rotational + translational + potential energy) falls in the range $(E, E + \delta E)$?

In all cases you may assume that the energy E is large compared to the spacing between energy levels.

3. This question treats an infinite square well with the potential $V_0(x) = 0$ for $-a/2 < x < a/2$, $V_0(x) = \infty$ for $x \leq -a/2$ or $x \geq a/2$.

A. A delta function $V_1 = -b\delta(x)$ is added to the potential, where b is positive so the delta function potential is negative. The new potential is $V_0 + V_1$. For exactly one value of b the ground state energy for this position will be zero: calculate that value of b. Sketch the ground state wavefunction for this value of b. Add to your sketch the wavefunctions for b slightly less, and slightly more, than this value, showing qualitatively how the wavefunction changes.

B. Now considering just V_0 (no delta function): two identical spin-1/2 particles (A and B) are bound in this potential. In addition to the spatial potential V_0, the particles interact via a term that depends on their spin: $V_2 = -c(\vec{S_A} \cdot \vec{S_B})$ where c is a positive number. For what values of c is the ground state of the system a singlet, and for what values is it a triplet?

4. Radiation by a white dwarf derives its energy from the thermal energy of its ions, since the electrons form a highly degenerate Fermi gas and cannot lose energy easily. The luminosity of a white dwarf can be shown to relate to its mass and core temperature according to $L = A(M/M_\odot)T^{3.5}$, where $M_\odot$ is the mass of our sun and $A = 0.2$ W/K$^{3.5}$.

A. Estimate the total heat capacity of a one solar mass white dwarf (radius = 7000 km) composed primarily of carbon.

B. How long would it take this white dwarf to cool from a core temperature of 10^7 K degrees to a temperature of 10^6 K degrees?

C. What would the surface temperature of the white dwarf be when its core temperature is 10^6 K?

Spring 2025 Physics Qualifying Exam
for Advancement to Candidacy
Part 2
May 9, 2025
13:00-15:15 PDT

If you are in the PhD in astronomy or PhD in medical physics programs, stop! This is the physics version of the exam. Please ask the proctor for the version appropriate for your program instead.

Do not write your name on your exam papers. Instead, write your student number on each page. This will allow us to grade the exams anonymously. We'll match your name with your student number after we finish grading.

This portion of the exam has 4 questions. Answer *any three* of the four. Do not submit answers to more than 3 questions—if you do, only the first 3 of the questions you attempt will be graded. If you attempt a question and then decide you don't want to it count, clearly cross it out and write "don't grade".

You have 2 hours and 15 minutes to complete 3 questions.

You are allowed to use one $8.5'' \times 11''$ formula sheet (both sides), and a handheld, non-graphing calculator.

Here is a possibly useful table of physical constants and formulas (see back of page as well):

absolute zero	0 K	-273°C
atomic mass unit	1 amu	1.661×10^{-27} kg
Avogadro's constant	N_A	6.02×10^{23}
Bohr radius of hydrogen atom	a_0	5.3×10^{-11} m
Boltzmann's constant	k_B	1.38×10^{-23} J/K
charge of an electron	e	1.6×10^{-19} C
distance from earth to sun	1 AU	1.5×10^{11} m
Laplacian in spherical coordinates	$\nabla^2\psi =$	$\frac{1}{r}\frac{\partial^2}{\partial r^2}(r\psi) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial\psi}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2\psi}{\partial\phi^2}$
magnetic field of dipole	$\vec{B}(\vec{r}) =$	$\frac{\mu_0}{4\pi}\left[\frac{3\hat{r}(\vec{m}\cdot\hat{r})-\vec{m}}{r^3}\right]$
mass of an electron	m_e	0.5110 MeV/c^2
mass of a neutron	m_n	1.67493×10^{-27} kg $= 939.5654$ MeV/c^2
mass of a proton	m_p	1.67262×10^{-27} kg $= 938.2721$ MeV/c^2
mass of the sun	M_{sun}	2×10^{30} kg
molecular weight of H_2O		18
Newton's gravitational constant	G	6.7×10^{-11} N m^2 kg^{-2}
permittivity of free space	ϵ_0	8.9×10^{-12} C^2 N^{-1}/m^2
permeability of free space	μ_0	$4\pi \times 10^{-7}$ N/A^2
Planck's constant	h	6.6×10^{-34} J·s
radius of curvature	$R =$	$\|\mathbf{v}\|^{\mathbf{3}}/\|\mathbf{v} \times \dot{\mathbf{v}}\|$
radius of the Earth	R_{earth}	6.4×10^6 m
radius of a neutron	$R_{neutron}$	3×10^{-16} m
speed of light	c	3.0×10^8 m/s
Stefan-Boltzmann constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
Stirling's approximation	$N!$	$e^{-N}N^N\sqrt{2\pi N}$

5. Neutrons having a magnetic moment of μ_n are placed at location $(0,0,0)$, polarized in the $+z$ direction, and are intended to precess in a uniform applied magnetic field of $\vec{B} = B_0\hat{x}$. Unfortunately a small ferromagnetic particle with a magnetic moment of $\vec{m} = m\hat{x}$ is located at $(-d,0,0)$. Calculate the precession frequency of the neutrons.

6. A small planet orbits a star of mass M. A cloud of dust with a uniform mass density ρ surrounds the star and extends past the planet's orbit.

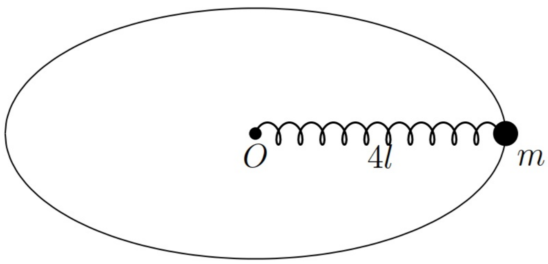
A. Calculate the orbital period of the planet as a function of the planet's distance from the star, assuming a circular orbit.

B. Now consider an orbit that is slightly non-circular, but has the same angular momentum, for which the planet's distance from the star varies as $R(t) = R_0(1+\zeta(t))$. Show that the orbit precesses. (Hint: calculate the effective potential $V(r)$ of this system — gravitational plus centrifugal contributions — and consider small oscillations around its minimum.)

7. In order to measure the magnetic field of the Earth, B_{earth}, you suspend a magnetized needle of fixed magnetization horizontally, aligning it with the magnetic North. When nudged, a small oscillation around this direction of magnetic North is induced. The period of this oscillation lets you almost calculate the strength of the magnetic field. What other parameters would you need to know in order to calculate B_{earth} from the period of oscillation? What other simple equipment, found in most experimental laboratories, could you use to determine these parameters, and what auxiliary experiments you would need to carry out with this equipment?

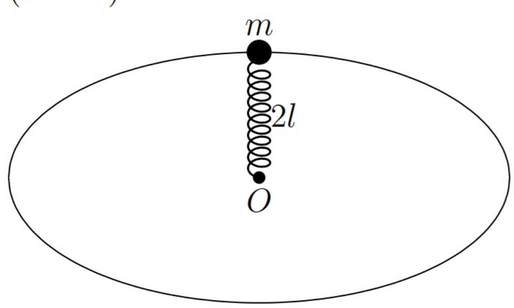
8. Consider a mass m free to move without friction on a horizontal table. This mass is attached to a fixed point O on the table by a stretchy spring. The spring has unstretched length l and a spring constant k. The mass is moving on a closed path as shown in the diagrams.

At time t_1, the mass is at its maximum distance from O, which is $4l$ (shown).



$t = t_1$

At time t_2, the mass is at its minimum distance from O, which is $2l$ (shown).



$t = t_2$

Compute the speed of the mass when it is at point A, which is $3l$ away from O in terms of l, k and m only. Also, compute the angle that the velocity makes with respect to the spring. What is the radius of curvature of the path at point A?