

Fall 2026 Physics Qualifying Exam
for Advancement to Candidacy
Part 1
September 2, 2026
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 invigilator 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 calculator incapable of internet access.

Here is a possibly useful table of physical constants and formulas:

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	$\nabla^2 \psi =$	$\frac{1}{r} \frac{\partial^2}{\partial r^2} (r\psi) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial \psi}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \psi}{\partial \phi^2}$
dipole radiation formula		$P_{rad} = \mu_0 \omega^4 \vec{p} ^2 / 12\pi c$
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
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 2D quantum mechanical system consists of three point masses, each with mass m , that are restricted to move only in the xy plane. The first mass is fixed rigidly at $(0, 0)$. The second is restricted to move along the x -axis, while the third can move in the plane. The interaction potential is:

$$V = \frac{k}{2} (d_{12}^2 + d_{13}^2 + d_{23}^2).$$

Here d_{ij} is the distance between mass i and mass j .

What is the ground-state energy of this system? (Ignore any contributions to the kinetic energy from coordinates that are constrained to equal 0.)

2. A source emits radiation isotropically in its rest frame S' with specific intensity I'_{ν} . Consider another frame S in which the source moves with velocity u along the $+x$ direction. A photon observed in frame S makes an angle θ with the direction of motion of the source. Define $\beta = u/c$ and let γ denote the Lorentz factor.

A. Starting from the Lorentz transformation of the photon 4-momentum, show that the observed photon frequency in frame S is related to the frequency in the source rest frame by $\nu = \delta \times \nu'$, where the Doppler factor is

$$\delta = \frac{1}{\gamma(1 - \beta \cos \theta)}.$$

B. Show that when $\gamma \gg 1$ and $\theta \ll 1$, the Doppler factor becomes

$$\delta \approx \frac{2\gamma}{1 + \gamma^2 \theta^2}.$$

C. Use the fact that I_{ν}/ν^3 is a relativistic invariant to conclude that the observed intensity is strongly concentrated inside a cone of characteristic angular size $\theta \sim 1/\gamma$. Relativistic jets in Active Galactic Nuclei often have $\gamma \sim 10$. Calculate the opening angle of the beam in degrees.

3. A tritium atom (${}^3\text{H}$, nuclear charge $Z = 1$) is in its electronic ground state. The nucleus undergoes beta decay,



so the nuclear charge abruptly becomes $Z = 2$. The emitted beta electron escapes and plays no further role, and the nuclear mass is essentially unchanged, so the atomic electron simply finds itself in a new Coulomb potential.

You may use the normalized hydrogenic wavefunctions

$$\psi_{100}(r) = \frac{1}{\sqrt{\pi}} \left(\frac{Z}{a_0} \right)^{3/2} e^{-Zr/a_0}, \quad \psi_{200}(r) = \frac{1}{4\sqrt{2\pi}} \left(\frac{Z}{a_0} \right)^{3/2} \left(2 - \frac{Zr}{a_0} \right) e^{-Zr/2a_0},$$

and $\int_0^\infty r^n e^{-br} dr = n!/b^{n+1}$.

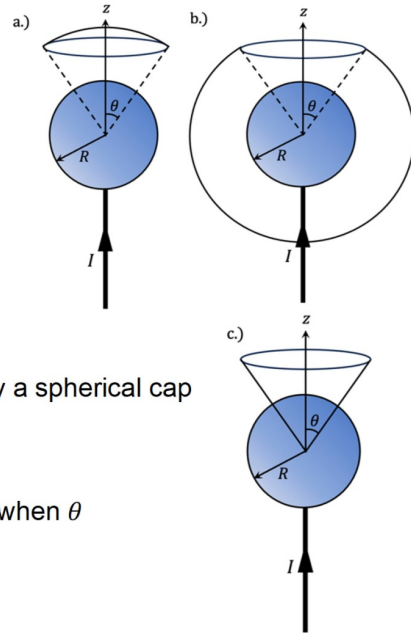
- (a) State the sudden approximation and the physical condition under which it is valid.
- (b) Calculate the probability that the electron is found in the ground state of the resulting ${}^3\text{He}^+$ ion. Give an exact expression and a number.
- (c) Calculate the probability that it is found in the $2s$ state. What can you say about the probability that the ion is left in *any* excited state, or is ionized altogether?
- (d) Justify the sudden approximation quantitatively here. The beta electron is emitted with kinetic energy up to 18.6 keV. Estimate the time it takes to leave the atom and compare it with the orbital period of the atomic electron. Comment on whether the fastest or the slowest beta electrons pose the greater problem.

4.

A conducting spherical shell of radius R centered at the origin is being charged by a steady current I flowing up the z -axis and connected to the “south pole” of the sphere, where it spreads out uniformly over the surface. The total charge on the sphere at time t is $Q(t) = It$. Find the magnetic field at a point (r, θ, ϕ) exterior to the sphere. First decide what direction you think $\mathbf{B}$ points, then apply the Ampère/Maxwell law in integral form to an appropriate Ampèrian loop:

$$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I_{enc} + \mu_0 \epsilon_0 \int \left(\frac{\partial \mathbf{E}}{\partial t} \right) \cdot d\mathbf{a}$$

- a) Use the surface bounded by the Ampèrian loop defined by a spherical cap north of the loop.
- b.) Use a spherical bowl south of the loop for a surface.
- c.) Use a cone with the vertex at the origin.
- d.) How do your results compare? What do your results say when θ approaches π ?



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5. Estimate the maximum mass of a neutron star. Remember that neutrons are spin-1/2 fermions.

6. Galileo demonstrated the law of falling with time by tying threads around an inclined plane, and rolling balls down it. The threads were spaced such that the clicks as the ball rolled over the threads kept time with a song he sang. He found that the spacing increase of the threads went as the square when the clicks occurred in time to the music.

He also argued that the falling of bodies was independent of the constituents of the bodies.

Consider two types of balls, one solid and one hollow. They roll down the plane without slipping. Do they roll down the inclined plane in the same times? What is the ratio of their times?

7. Let $f(\vec{x}, \vec{v})$ denote the phase space density of particles in a gas as a function of the position $\vec{x}$ and velocity $\vec{v}$ of particles in the gas. In this problem we will model the position and velocity distributions of stars in a spherically symmetric galaxy by treating each star as a “particle”.

The isothermal sphere distribution has the form

$$f(r, v) = \frac{n_0}{(2\pi\sigma^2)^{3/2}} \exp\left(-\frac{\frac{1}{2}v^2 + \Phi}{\sigma^2}\right).$$

Here v is the magnitude of the velocity, $\Phi(r)$ is the gravitational potential energy per unit mass, and σ^2 acts as an effective “temperature” of this gas of stars. n_0 normalizes the distribution.

A. Calculate the number density $n(r)$ of stars as a function of n_0 , σ , and $\Phi(r)$.

B. Assuming that all stars have a mean mass $\bar{m}$, use Poisson’s equation to write down a differential equation for the mass density $\rho(r)$ in this system.

C. Solve for $\rho(r)$. (Hint: try a power law solution.)

8. The Swift gamma-ray telescope is currently in a decaying orbit due to atmospheric drag. Presently it is in a circular orbit at an elevation of 400 km, where the air density is $\sim 3 \times 10^{-12} \text{ kg/m}^3$. Swift has a mass of 800 kg and consists of a cylinder with diameter 1.6 m and length 5.5 m, and solar panels on either side with dimensions of $1.3 \text{ m} \times 5 \text{ m}$ (see figure).

Do an order of magnitude estimate of the rate at which the telescope is currently losing altitude.

