

Fall 2021 Physics Qualifying Exam
for Advancement to Candidacy

Part 2

September 1, 2021

12:30-14:45 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 download 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 2.25 hours 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:

absolute zero	0 K	-273°C
atomic mass unit	1 amu	1.66×10^{-27} kg
Avogadro's constant	N_A	6.02×10^{23}
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	0.511 MeV/c ²
mass of hydrogen atom	m_H	1.674×10^{-27} kg
mass of a neutron	m_n	1.675×10^{-27} kg
mass of a proton	m_p	1.673×10^{-27} kg
mass of the sun	M_{sun}	2×10^{30} kg
molecular weight of H ₂ O		18
Newton's gravitational constant	G	6.7×10^{-11} N m ² kg ⁻²
nuclear magneton	μ_N	5×10^{-27} J/T
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	$N!$	$e^{-N} N^N \sqrt{2\pi N}$

5. Neutrons experience an attractive interaction described by a potential energy $V(r)$, where r is the distance between the neutrons. An approximate form for $V(r)$ is:

$$V(r) = \begin{cases} +\infty & r < 0.5 \text{ fm} \\ -V_0 & 0.5 < r < 3 \text{ fm} \\ 0 & 3 \text{ fm} < r \end{cases}$$

Here V_0 is a positive constant, and $1 \text{ fm} = 10^{-15} \text{ m}$. Determine the minimum value of V_0 , in MeV, for which a bound state with orbital angular momentum $\ell = 0$ exists. If V_0 is large enough that such a bound state exists, what is the *total* angular momentum of the system, and why?

Hint: the Laplacian operator in spherical coordinates is given on the first page of this exam. The substitution $u(r) = r\psi(r)$ can simplify the problem considerably.

6. Consider a particle of mass m trapped between two walls. We'll solve this problem in 1D, so the two walls effectively make an 1D infinite square well potential confining the particle. The distance between the walls is D .

- A. What is the quantum mechanical energy of the particle in the n^{th} energy level?
- B. Using your answer to Part A, what is the force on the walls when the particle is in the n^{th} level?
- C. What is the average force on the walls due to a classical particle, whose kinetic energy matches your answer to Part A, bouncing back and forth between the walls? (Again assume this is a 1D problem.)

7. A comet is spotted in an orbit around the sun. When spotted, the comet is 10^{11} m from the sun, heading 20 degrees away from the direct path to the sun at a speed of 10^4 m/s. What is the closest approach of the comet to the sun in its orbit?

8. A car begins moving on a horizontal road, with a door accidentally left open with an initial angle ϕ_0 (where $\phi = 0$ indicates the door is closed). The motion of the car is described by known function $x(t)$. The rectangular door has a mass m , length L , negligible thickness and uniform mass density, and is allowed to rotate a full 360-degree turn around its vertical hinge. You may ignore air resistance in this problem.

- A. Find a differential equation for the angle of the door with the car, in terms of the known $x(t)$ of the car.
- B. If the door is allowed to swing into the car (remember, the hinge allows full rotation) and the car is moving with constant acceleration, the door may oscillate about an equilibrium position. For small oscillations, what is the frequency of oscillation?

