Fall 2021 Physics Qualifying Exam
for Advancement to Candidacy
Part 1
September 1, 2021
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 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.

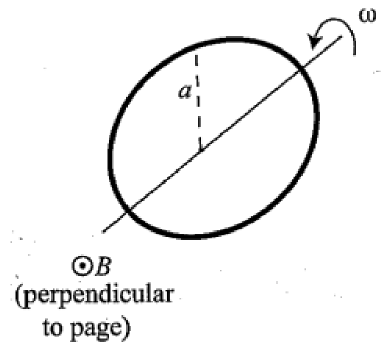
You are allowed to use one $8.5'' \times 11''$ formula sheet (both sides), and a handheld, non-graphing calculator.

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_2O		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	$N!$	$e^{-N}N^N\sqrt{2\pi N}$

1.

A conducting loop of radius a, resistance R, and moment of inertia I is rotating around an axis in the plane of the loop, initially at an angular frequency ω_0. A uniform static magnetic field B is applied perpendicular to the rotation axis (see figure). (a) Calculate the rate of kinetic energy dissipation, assuming it all goes into Joule heating of the loop resistance. (b) In the limit that the change in energy per cycle is small, derive the time dependence of the angular velocity ω. In particular, how long will it take for ω to fall to $\frac{1}{e}$ of its initial value? You may ignore any effects relating to self-inductance.



2. There is a theorem, called Earnshaw's theorem, which states that it is not possible to build a device which levitates an electric charge in a gravitational field in vacuum by using static electric fields alone. However you configure the fields, if the fields are non-zero, the system is at best meta-stable. Find a proof of Earnshaw's theorem. Assume the simplest case of equilibrium of a single point charge.

3. Consider an equilibrium magnetic system in fixed magnetic field $B = 0$. The free energy $G(m, T)$ of the system as a function of magnetization density m can be written as:

$$G(m, T) = a + \frac{b}{2}m^2 + \frac{c}{4}m^4 + \frac{d}{6}m^6$$

In some relevant range of temperatures T , the coefficients b and d can be taken to be positive constants, $b, d > 0$, while c depends on the temperature and it goes through 0 at some temperature T^* in this range,

$$c(T) = c_0(T - T^*) \ , \quad c_0 > 0$$

In this regime of temperatures, the free energy G describes a phase transition, in which the system transitions from the state with no magnetization, $m = 0$, to the magnetized state with $m = m_0 \neq 0$ at some temperature T_0. Find the temperature T_0 at which the phase transition occurs. What is the order of this phase transition? Find the magnitude of the magnetization m_0 appearing at the transition temperature T_0. Calculate the latent heat of the transition.

4. A flat plate with area A and negligible thickness sits inside an classical ideal gas with pressure P, temperature T, and molecular mass m. Calculate the rate at which molecules strike the plate. You may ignore edge effects. Do a full exact calculation, not just an order of magnitude estimate.