Introduction NEXT

Wednesday 08-04-2015, 13.00-16.00

Use a **seperate** sheet for each of the three main questions. Write your name and student number on **all** sheets. You can earn up to 3 points for each main question (theory / nano / experimental); the total number of points is 9 (leading to a grade between 1 and 10).

QUESTION 1: BLACK HOLES

The space-time around a black hole of mass M is described by the Schwarzschild metric:

$$d\tau^2 = (1 - \frac{2M}{r})dt^2 - \frac{dr^2}{1 - \frac{2M}{r}} - r^2 d\theta^2 \,.$$

1.1 Explain in words what the coordinates r and t parametrize: how are they defined / what do they measure?

1.2 Suppose there is a light source with frequency f_0 at infinity. What frequency is measured by an observer at coordinate r?

1.3 What happens in the previous question when one takes $r < 2M$? Explain the physics of your result.

1.4 Suppose there is a freely falling object that starts at rest at infinity. What speed does an observer at coordinate r measure when the object passes the observer? Derive your answer.

Distribution of points: .5+.5+.5+1.5 =3.0.

Exam NExT– Experimental Particle Physics

Please use a separate sheet of paper – put down your Name and Student number.

There are 3 points you can score for the questions concerning Experimental Particle Physics

Question P1: Fusion

In the sun helium nuclei (^{4}He) are produced from 4 protons (p). Energy is released in this process. Let's have a closer look:

(a) Give an equation for the reaction that summarizes the process. How much energy *is released* in this process? In which ~~from~~ form is this energy released? (1/2 point)

(b) A helium nucleus (^{4}He) has 2 protons and two neutrons. How can a proton become a neutron? What does the associated process mean for the sun? (1/4 point)

(c) Which fundamental forces are involved in the reaction you give in part (a)? (1/4 point)

(d) How much (mass) hydrogen is needed in one year to produce 12 GW of electric energy (this is approximately what the Netherlands consume)? Assume that thermal energy can be converted with 30% efficiency into electricity. (1/2 point)

Question P2: Particles and Forces

It is a great success of theoretical physics that one single model can describe all confirmed observations in particle physics.

(a) What is the name of this theory? How many fundamental forces are known in this theory? What are their names? Which fundamental matter particles exist in this theory? (1/2 point)

(b) What is the difference between the fundamental fermions and the fundamental bosons, i.e. what is the role of fermions and bosons in this model? (1/4 point)

(c) In a cosmic ray event a proton (p) can hit the upper atmosphere. What can happen there, i.e. with which particles can the proton collide? Which fundamental forces can then be involved in each of the possible collisions? (1/4 point)

(d) In a particle collider (such as LHC at CERN) accelerated particles can collide. Let's assume two colliding proton beams of 100 GeV energy each. Can we observe the production of (i) a proton- antiproton pair, (ii) two negative muons , (iii) a negative muon and a positron, and

(iv) one Z boson only? (Assume nothing else is created.) Give 1 line of reasoning for your judgment in each case. (1/2 point)

(proton mass $m_p =$ 938.272 046 MeV/c^2 = 1.672 621 77 ▪ 10^{-27} kg ; neutron mass $m_n =$ 939.565 379 MeV/c^2 ; m_{4He} = 3727.379 240 MeV/c^2 ; electron mass m_e = 0.510 998 928 MeV/c^2 ; neutrino masses $m_\nu = 0$ {for this purpose we can safely neglect neutrino masses} ; 1 J = 1.60217653 ▪ 10^{-19} eV; 1 year = π ▪ 10^7 s ; muon mass m_μ = 105.658 371 5MeV/c2 ; Z boson mass m_z = 91.1876 GeV/c^2 .)

Questions on the material treated in Introduction NEXT –Theme I: Nanophysics

Wednesday April 8, 2015. You have one hour for each of the three parts (Nanophysics, Experimental Particle Physics and Theoretical Physics) of the exam for a total of 3 hours.

Please use different sheets for each of the three parts of the exam since each one will be corrected by a different lecturer. Please write your name and student number on each sheet of paper!

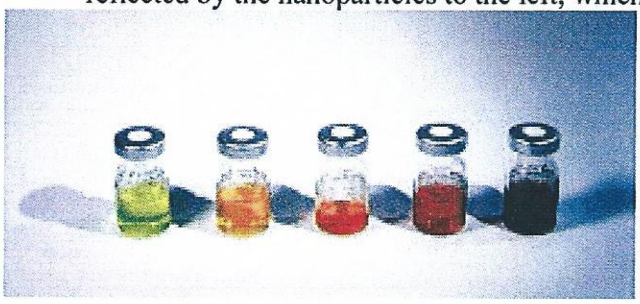
Please answer to each question with full sentences. Motivate your answer whenever relevant. Each question below will be awarded with maximum 0.5 points to make up the 3 points for the nanophysics part of Introduction NEXT.

1) Describe two examples where the use of nanometer-sized objects responds to societal demands: better health care, better care for clean earth, water and air, new industrial products, improved information & communication services. Explain which nano-object is used and for what purpose.

2) The distance between the nuclei of two silver atoms is about 4 Å (1 Å = 10^{-10} m). How many nanometers is that? How many silver atoms are needed to make a 1.5 μm long atomic wire?

3) What is the electronic structure of Phosphorus, Potassium and Krypton? How many valence electrons does each of these elements have? Explain why a 1 cm^3 Potassium crystal is a metal.

4) What determines the optical properties of nanoparticles made out of insulating material like the ones you see in the picture below? Explain why the different size of the nanoparticles gives rise to different colour. What is the energy of the photons reflected by the nanoparticles to the left, which appear light green?



Solutions of nanoparticles with different size

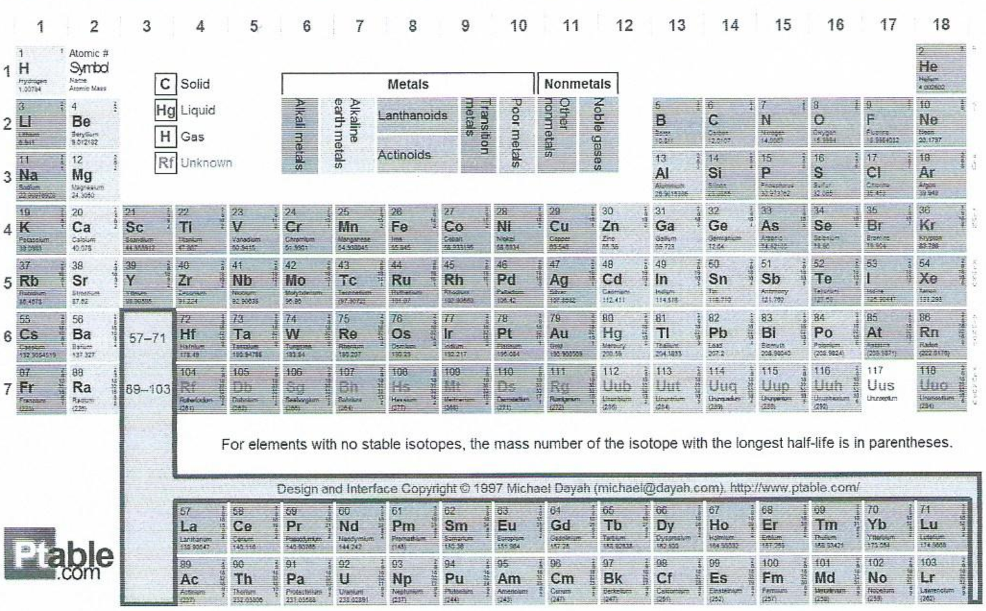
4) Draw the conductance of an electron channel as a function of the width of the channel (a) for a macroscopic channel; (b) for a channel of width below 1 μm and explain the different behaviours. How does a scanning tunneling microscope work? What can one do with a scanning tunnelling microscope in addition to imaging?

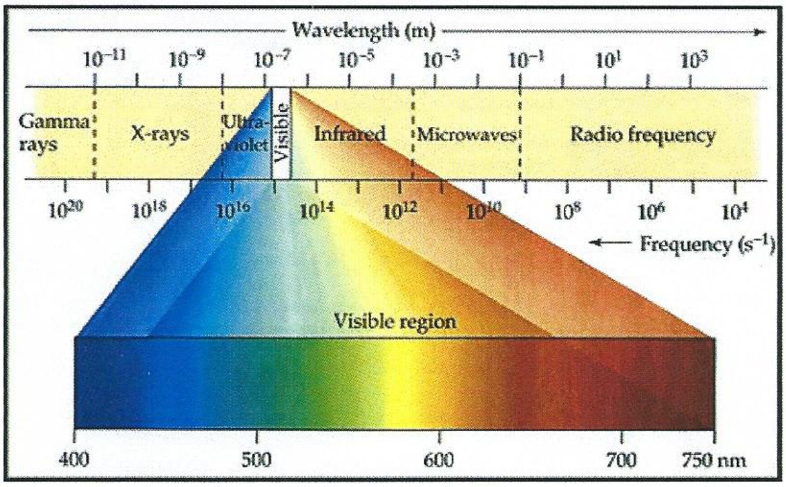
Please also consider the tables and graph on the attached page for your answers.

A list of some fundamental constants, definitions and relations

Constant	Symbol	Approximate Value
Speed of light in vacuum	c	3.00×10^{8} m/s
Permeability of vacuum	μ_0	12.6×10^{-7} H/m
Permittivity of vacuum	ϵ_0	8.85×10^{-12} F/m
Magnetic flux quantum	$\phi_0 = \frac{h}{2e}$	2.07×10^{-15} Wb
Electron charge	e	1.602176×10^{-19} C
Electron mass	m_e	9.11×10^{-31} kg
Proton mass	m_p	1.673×10^{-27} kg
Neutron mass	m_n	1.675×10^{-27} kg
Proton-electron mass ratio	$\frac{m_p}{m_e}$	1836
Boltzman constant	k_b	$1.3806503 \times 10^{-23}$ m^2 kg s^{-2} K^{-1}
Boltzman constant [cm^{-1}]	k_b	0.6950356 cm^{-1}
planck constant/2π	$\hbar$	1.05457×10^{-34} J s
atomic mass unit (a.m.u.)	amu	$1.66053886 \times 10^{-27}$ kg
electron volt to Joule	1 eV	1.602176×10^{-19} J
electron volt to wavenumber	1 eV	8065.395 cm^{-1}
wavenumber to frequency	1 cm^{-1}	29.98 GHz

Periodic Table of Elements




Wavelength (m)
10⁻¹¹ 10⁻⁹ 10⁻⁷ 10⁻⁵ 10⁻³ 10⁻¹ 10¹ 10³
Gamma rays
X-rays
Ultra-violet
Visible
Infrared
Microwaves
Radio frequency
10²⁰ 10¹⁸ 10¹⁶ 10¹⁴ 10¹² 10¹⁰ 10⁸ 10⁶ 10⁴
Frequency (s⁻¹)
Visible region
400 500 600 700 750 nm