

## 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:

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

- 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 ( ${}^4\text{He}$ ) 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 ~~form~~<sup>form</sup> is this energy released? (1/2 point)
- (b) A helium nucleus ( ${}^4\text{He}$ ) 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  $m_p = 938.272\,046\text{ MeV}/c^2 = 1.672\,621\,77 \cdot 10^{-27}\text{ kg}$ ; neutron mass  $m_n = 939.565\,379\text{ MeV}/c^2$ ;  $m_{\text{He}} = 3727.379\,240\text{ MeV}/c^2$ ; electron mass  $m_e = 0.510\,998\,928\text{ MeV}/c^2$ ; neutrino masses  $m_\nu = 0$  {for this purpose we can safely neglect neutrino masses};  $1\text{ J} = 6.241\,509\,35 \cdot 10^{18}\text{ eV}$ ;  $1\text{ year} = \pi \cdot 10^7\text{ s}$ ; muon mass  $m_\mu = 105.658\,371\,5\text{ MeV}/c^2$ ; Z boson mass  $m_z = 91.1876\text{ GeV}/c^2$ .)

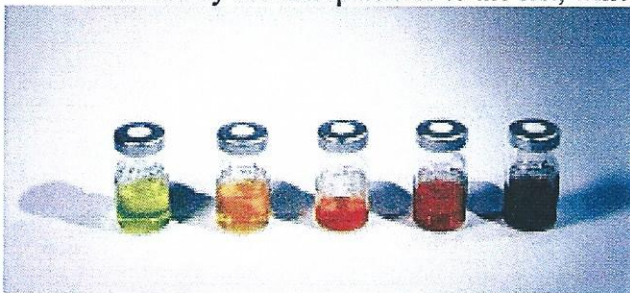
## Questions on the material treated in Introduction NEXT –Theme I: Nanophysics

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  $4 \text{ \AA}$  ( $1 \text{ \AA} = 10^{-10} \text{ m}$ ). How many nanometers is that? How many silver atoms are needed to make a  $1.5 \text{ \mu m}$  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  $1 \text{ cm}^3$  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  $1 \text{ \mu m}$  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	$c$	$3.00 \times 10^8$ m/s
Permeability of vacuum	$\mu_0$	$12.6 \times 10^{-7}$ H/m
Permittivity of vacuum	$\epsilon_0$	$8.85 \times 10^{-12}$ F/m
Magnetic flux quantum	$\phi_0 = \frac{h}{2e}$	$2.07 \times 10^{-15}$ Wb
Electron charge	$e$	$1.602176 \times 10^{-19}$ C
Electron mass	$m_e$	$9.11 \times 10^{-31}$ kg
Proton mass	$m_p$	$1.673 \times 10^{-27}$ kg
Neutron mass	$m_n$	$1.675 \times 10^{-27}$ kg
Proton-electron mass ratio	$\frac{m_p}{m_e}$	1836
Boltzman constant	$k_b$	$1.3806503 \times 10^{-23}$ m <sup>2</sup> kg s <sup>-2</sup> K <sup>-1</sup>
Boltzman constant [cm <sup>-1</sup> ]	$k_b$	$0.6950356$ cm <sup>-1</sup>
Planck constant/2 $\pi$	$\hbar$	$1.05457 \times 10^{-34}$ J s
atomic mass unit (a.m.u.)	amu	$1.66053886 \times 10^{-27}$ kg
electron volt to Joule	1 eV	$1.602176 \times 10^{-19}$ J
electron volt to wavenumber	1 eV	$8065.395$ cm <sup>-1</sup>
wavenumber to frequency	1 cm <sup>-1</sup>	29.98 GHz

# Periodic Table of Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.00794	2 He Helium 4.002602																
3 Li Lithium 6.941	4 Be Beryllium 9.012182	5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180										
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 52.004	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.906	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.905	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.60	53 I Iodine 126.905	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.222	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (286)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (285)	117 Uus Ununseptium (286)	118 Uuo Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium (237)	94 Pu Plutonium 244	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium 251	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)

