PC2302

ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Atoms and Nuclei

30th May 2001, 2.00 p.m. - 3.30 p.m.

Answer **ALL** parts of question 1 and **TWO** other questions

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Electronic calculators may be used, provided that they cannot store text.

The numbers are given as a guide to the relative weights of the different parts of each question.

P.T.O.

1. (a) What are the electronic configurations of the ground states of the fluorine, neon and sodium atoms? [5 marks]

(b) State Moseley's Law for x-ray energies and briefly describe its origin. [5 marks]

(c) Briefly describe the mechanism of covalent bonding in diatomic molecules. [5 marks]

(d) A sample of ^{222}Rn gas contains 10^6 atoms. Estimate how many days it would take for the number of Rn atoms in the sample to decrease to 100, given that their half-life is 3.82 days. [5 marks]

(e) What is the dependence of the radius R of a nucleus on the mass number A? Show that this is in accord with the nucleus having constant density. [5 marks]

(f) Give one example of a fission reaction in which energy is released. [5 marks]

2. Outline (briefly and qualitatively, without giving detailed equations) how Bohr used the Correspondence Principle to derive an expression for the energies of highly excited states of the hydrogen atom. [10 marks]

Describe how the spin and orbital angular momentum couple for the electron of the hydrogen atom and give the full set of quantum numbers for the states of the electron. Explain why this type of coupling is usually stronger than couplings to external magnetic fields. [10 marks]

Given that the wavefunction of the ground state of hydrogen is proportional to e^{-r/a_0}, where a_0 is the Bohr radius, find the most probable distance between the electron and the proton. [10 marks]

3. Sketch the forms of the spatially symmetric and anti-symmetric wavefunctions for the lowest electronic states of H_2^+ molecule. Which of these has the lower energy, and why? [10 marks]

Sketch the typical potential energy function for a diatomic molecule that is covalently bonded and indicate on it the dissociation energy and equilibrium inter-nuclear separation, giving their typical values.

[5 marks]

Explain how the form of the potential energy function can be used to deduce the vibrational and rotational energies of a homonuclear diatomic molecule. [10 marks]

The lowest two rotational energy levels of H_2 are separated by 0.015 eV and the lowest two vibrational energy levels are separated by 0.585 eV. Deduce the form of the potential energy function in the vicinity of the potential minimum. [5 marks]

4. Sketch an annotated graph with approximate scales which shows the dependence on the mass number A of the binding energy per nucleon of the stable nuclides. [10 marks]

Use this sketch to explain why

(a) fusion processes are usually possible only for nuclides of low A, [5 marks]

(b) fission processes are usually possible only for nuclides of high A. [5 marks]

Suppose that the fusion reaction $D + D \rightarrow T + p$ can occur if the centres of the deuterons are within 1 fm of each other. If the two deuterons collide head-on, with equal and opposite velocity, what is the minimum energy that they must have for the reaction to occur (disregarding any tunnelling effects), and what then are the kinetic energies of the T and p that are formed? The atomic masses of ${}_1^1H$, ${}_1^2H$ and ${}_1^3H$ are 1.007825, 2.014102 and 3.016050 u respectively, where the mass unit u is equivalent to 931.5 MeV. [10 marks]