Question 21 **(22 marks)**

Scanning electron microscopy (SEM): a powerful surface probing-technique

Scanning electron microscopes use an energetic electron beam to examine the surface of objects on a very small scale. The basic principle of the electron microscope is similar to that of the optical microscope, but, due to the wavelength of visible light, the resolution of optical microscopy is limited to the micrometre range. However, the resolution of an electron microscope depends on the energy of electrons and can easily reach the nanometre range. Thus, the magnification of an electron microscope can be as high as 1 000 000 times, while the magnification of an optical microscope is limited to about 1200 times.

The major components of an electron microscope are shown on page 35. The first section at the top of the diagram contains the electron gun, consisting of a filament to create electrons and a positively-charged anode plate that attracts and accelerates the electrons. With a large potential difference of up to 100 kV, a high-energy electron beam is directed toward the sample.

The electron beam manipulation component consists of a condenser lens, an objective lens and apertures located in the middle section of the microscope column. These control the size, shape and position of the electron beam on the surface of a test sample.

The electron beam interacts with the surface of the sample, resulting in several physical processes, such as backscattered electrons, secondary electrons, X-rays, cathode luminescence, current flow in the sample and transmitted electrons. All of these are very useful in determining the surface characteristics and composition of a sample using the various detector systems.

One such detector examines the range of frequencies of X-rays emitted from the sample during bombardment by the electron beam of an electron microscope. The information is used to identify the elemental composition of the sample.

(a) An electron is accelerated to $0.189c$ by the SEM.

(i) Ignoring relativistic effects, calculate the accelerating potential needed to achieve this velocity. (4 marks)

(ii) Ignoring relativistic effects, calculate the wavelength of this electron. (3 marks)

Answer ____________________ m

(b) Infer what information the detectors are able to measure to allow researchers to determine the composition of the material. (3 marks)

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An ultra-high voltage electron microscope (UHVEM) Hitachi H-3000 was installed in 1997 at Osaka University in Japan. The electron acceleration voltage of the H-3000 is in the range from 500 kV to 3500 kV, which enables researchers and scientists to investigate three-dimensional microstructures on an atomic scale from nanometres to picometres.

(c) The H-3000 used an acceleration voltage of 2000 kV to accelerate an electron from rest.

(i) Calculate the speed of the electron according to the classic model of energy conservation. (3 marks)

Answer ____________________ m s^{-1}

(ii) Explain the behaviour of the electron, taking relativistic effects into account. (3 marks)

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The diagram below shows a simple model of a condenser lens (magnetic lens). Assume the magnetic field is 3.5×10^{-3} T in the centre region and runs parallel to the axis of the electron beam. The electron has a spiral trajectory along the axis as shown. The electron has a speed of 6.3×10^{7} m s^{-1} and its circular component (perpendicular to the electron beam axis) is about 1% of this speed.

(d) Estimate the maximum cross-sectional diameter of the electron beam. For simplicity, assume circular motion of electrons due to the magnetic field. Express your answer in the appropriate significant figures. (5 marks)

Answer ______________________ m

(e) Estimate the expected magnification of the H-3000. (1 mark)