1)

**(a)** A patient has an X-ray scan taken in hospital. The high-energy X-ray photons interact with the atoms inside the body of the patient.

Explain what is meant by a *photon* and state **one** of its main properties.

...........................................................................................................................

...........................................................................................................................

........................................................................................................................... **[2]**

**(b)** An X-ray tube operates using a 150 kV supply. X-ray photons are produced inside the tube when a beam of high-speed electrons accelerated from the cathode collide with the metal anode. About 99% of the total kinetic energy of the electrons at the anode is converted into heat energy which heats the anode. The remaining energy is transformed into the energy of the X-ray photons.

The current in the electron beam between the cathode and the anode is 4.8 mA.

**(i)** Show that the number of electrons incident at the anode per second is $3.0 \times 10^{16}\,s^{-1}$.

**[1]**

**(ii)** The anode is made from metal of specific heat capacity $140\,J\,kg^{-1}\,K^{-1}$. It has a mass of 8.6 g. The X-ray tube is switched on. Calculate the initial rate of increase of temperature of the anode.

rate of temperature increase = ............................................ $°C\,s^{-1}$ **[3]**

**(iii)** A single electron is responsible for producing an X-ray photon. Calculate the shortest wavelength of the X-rays produced from the X-ray tube.

wavelength = ...................................................... m **[2]**

**(c)** An X-ray scan of the heart and its blood vessels shows very poor contrast. Describe and explain a technique that can be used to reveal these blood vessels in an X-ray scan.

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

.............................................................................................................................. **[2]**

2)

**(a)** X-rays are produced in an X-ray tube when fast moving electrons hit a metal target.

Fig. 7.1 shows a typical graph of intensity $I$ against wavelength $\lambda$ of X-rays emitted by an X-ray tube.

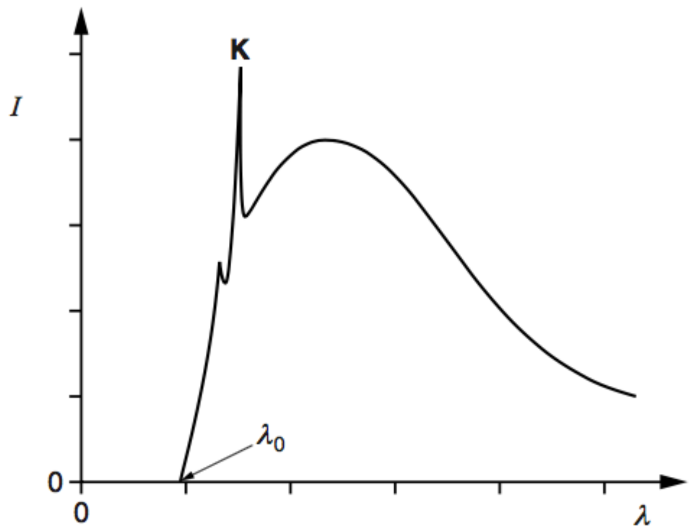


**Fig. 7.1**

High-speed electrons colliding with the atoms in the target metal can remove electrons from these atoms. The removal of such electrons creates 'gaps' in the lower energy levels of these atoms. These gaps are quickly filled by electrons in the higher energy levels making transitions to these lower energy levels. The electrons lose energy which is released as photons with particular wavelengths. These emission spectral lines are shown by the high intensity peaks such as **K** shown in Fig. 7.1.

Fig. 7.2 shows three of the energy levels, **A**, **B** and **C**, for the metal atoms of the target. The electron transition shown produces the peak **K**.

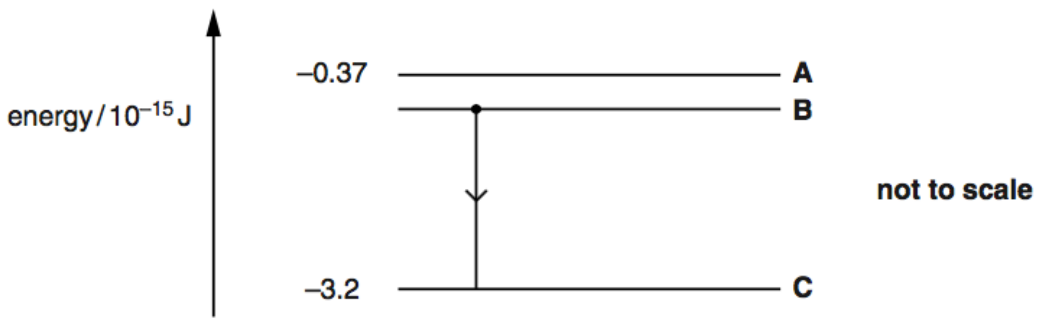


**Fig. 7.2**

**(i)** Explain what is meant by an *energy level* of an atom.

...........................................................................................................................

...........................................................................................................................

........................................................................................................................... **[1]**

**(ii)** The peak **K** occurs at a wavelength of $7.2 \times 10^{-11}$ m. Calculate the value of the energy level **B**.

value of energy level = ........................................................ J **[3]**

**(iii)** In Fig. 7.1, the shortest wavelength $\lambda_0$ produced from an X-ray tube depends on the accelerating potential difference $V$. The maximum kinetic energy of a single accelerated electron is equal to the energy of a single X-ray photon of wavelength $\lambda_0$. Explain how $\lambda_0$ from the X-ray tube changes when the accelerating potential difference of the X-ray tube is **doubled**.

..........................................................................................................................

..........................................................................................................................

.......................................................................................................................... **[2]**

**(b)** X-rays are used to scan the human body. A parallel beam of X-rays is incident on a muscle. The attenuation (absorption) coefficient $\mu$ for X-rays in muscle is $0.96\,\text{cm}^{-1}$.

**(i)** Calculate the fraction of X-ray intensity **absorbed** by 2.3 cm of muscle.

fraction = ........................................................ **[3]**

**(ii)** The attenuation coefficients for X-rays in bone and fat are $2.8\,\text{cm}^{-1}$ and $0.90\,\text{cm}^{-1}$ respectively. Two X-ray images are taken, one with bone and muscle and another with muscle and fat. State and explain which image will give better contrast.

..........................................................................................................................

..........................................................................................................................

.......................................................................................................................... **[1]**

**[Total: 10]**

3)

**(a)** Fig. 8.1 shows a B-scan image of an ultrasound scan of a 12 week foetus.


**Fig. 8.1**

The outline of the head of the foetus can be seen in Fig. 8.1. Describe and explain the principles of a B-scan.

*In your answer you should make clear how it is possible to distinguish the boundaries between different materials.*

.......................................................................................................................................... **[3]**

**(b)** Fig. 8.2 shows an image of the brain using a positron emission tomography (PET) scanner.

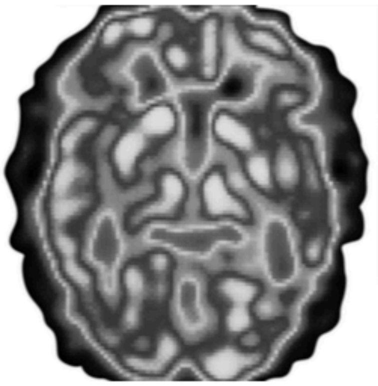

**Fig. 8.2**

The lighter regions in Fig. 8.2 show the active areas of the brain. Fluorine-18 is a common tracer injected into a patient before a PET scan.

Explain the basic principles of PET scanning, including how the image is formed.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[4]**

**[Total: 7]**

4)

**(a)** Fig. 8.1 shows an image of a patient from a gamma camera scan.

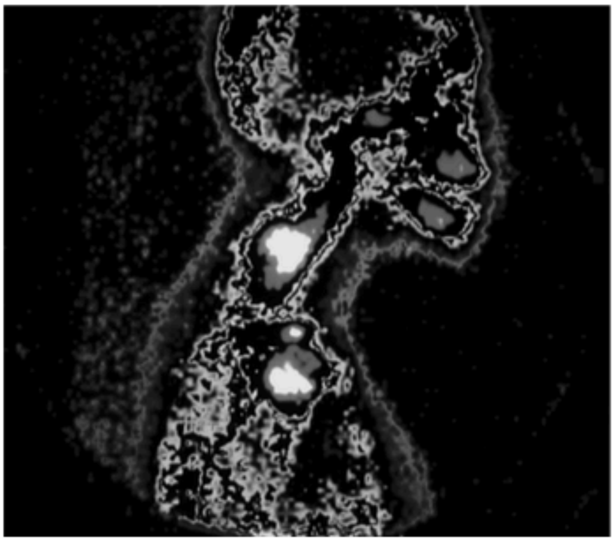

**Fig. 8.1**

The radioactive gamma-emitting tracer technetium-99m was injected into the patient before the scan. The image shows the distribution and intensity of gamma radiation emitted.

Discuss the advantages of using a gamma-emitting tracer in the patient rather than a beta-emitting tracer.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................. **[2]**

**(b)** Many hospitals are equipped with computerised axial tomography (CAT) scanners.

Describe how the components of a CAT scanner are used to produce a three-dimensional image of a patient.

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

................................................................................................................................ **[5]**

5)

**(a)** State **two** main properties of X-ray photons.

..........................................................................................................................................

..........................................................................................................................................

.......................................................................................................................................... **[2]**

**(b)** Fig. 7.1 shows an X-ray photon interacting with an atom to produce an electron-positron pair in a process known as pair production.

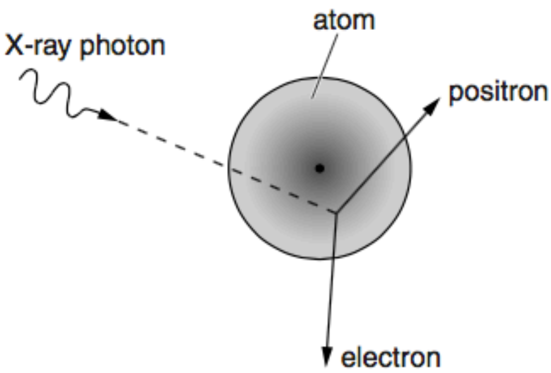


**Fig. 7.1**

Calculate the maximum wavelength of X-rays that can produce an electron-positron pair.

wavelength = ....................................................... m **[3]**

**(c)** Name an element used as a contrast material in X-ray imaging. Explain why contrast materials are used in the diagnosis of stomach problems.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.......................................................................................................................................... **[3]**

**[Total: 8]**

6)

**(a)** State **two** main properties of ultrasound.

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[2]**

**(b)** Describe how the piezoelectric effect is used in an ultrasound transducer both to emit and receive ultrasound.

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[2]**

**(c)** Explain why a gel is used between the ultrasound transducer and the patient's skin during a scan.

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[2]**

**(d)** Explain a method using ultrasound to determine the speed of blood in an artery in the arm.

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[4]**

**[Total: 10]**

7)

**(a)** Describe the *piezoelectric effect.*

..........................................................................................................................................

.......................................................................................................................................... **[1]**

**(b)** Describe how ultrasound scanning is used to obtain diagnostic information about internal structures of a body. In your description include the differences between an A-scan and a B-scan.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.......................................................................................................................................... **[4]**

**(c)** Fig. 7.1 shows the speed of ultrasound, density and acoustic impedance for muscle and bone.

| material | speed of ultrasound / $m\,s^{-1}$ | density / $kg\,m^{-3}$ | acoustic impedance / $10^6\,kg\,m^{-2}\,s^{-1}$ |
|---|---|---|---|
| muscle | 1590 | 1080 | 1.72 |
| bone | 4080 | 1750 | 7.14 |

**Fig. 7.1**

**(i)** Show that the unit for acoustic impedance is $kg\,m^{-2}\,s^{-1}$.

**[1]**

**(ii)** An ultrasound pulse is incident at right angles to the boundary between bone and muscle. Calculate the fraction of reflected intensity of the ultrasound.

fraction of reflected intensity = ........................................................ **[2]**

**(iii)** What is meant by *acoustic impedance matching*? Explain why a gel is used to produce an effective ultrasound image.

..............................................................................................................................

..............................................................................................................................

..............................................................................................................................

........................................................................................................................ **[2]**

**(iv)** The frequency of the ultrasound in the muscle is 1.2 MHz. Calculate the wavelength of the ultrasound in millimetres (mm).

wavelength = ................................................ mm **[2]**

**(v)** Suggest why it is desirable to have ultrasound of short wavelength for a scan.

..............................................................................................................................

..............................................................................................................................

........................................................................................................................ **[1]**

**[Total: 13]**

8)

**(a)** Describe the use of image intensifiers and contrast media when X-rays are used to produce images of internal body structures.

*In your answer, you should make clear how the appearance of the image is linked to the techniques used.*

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[5]**

**(b)** A student suggests an image intensifier uses the photoelectric effect. Explain why this suggestion is **incorrect**.

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[1]**

**(c)** **(i)** Explain how the production of a CAT scan image differs from that of a simple X-ray image.

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[2]**

**(ii)** Describe the advantages of a CAT scan compared to an X-ray image.

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[2]**

**Total: [10]**

9)

**(a)** Describe in simple terms how X-ray photons are produced in a hospital X-ray machine.

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[2]**

**(b)** Fig. 7.1 shows a simple X-ray intensifier screen.

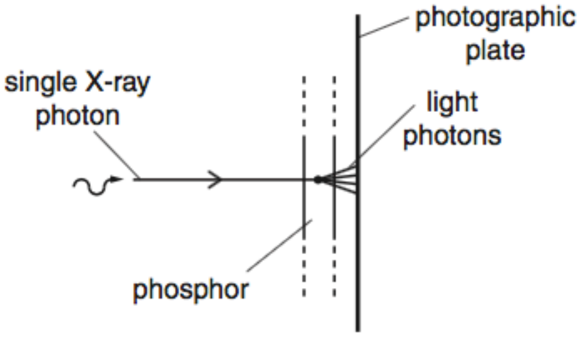


**Fig. 7.1**

A bright X-ray image can be produced using an image intensifier. A single X-ray photon incident on the phosphor produces about a thousand photons of visible light. The photons of visible light produce an image on a photographic plate.

**(i)** Explain what is meant by a *photon*.

..........................................................................................................................................

.................................................................................................................................... **[1]**

**(ii)** Explain why an X-ray photon has greater energy than a photon of visible light.

..........................................................................................................................................

.................................................................................................................................... **[1]**

**(c)** In an X-ray machine, accelerated electrons hit a metal target. Most of the kinetic energy of the electrons is converted into heat, but a small amount is converted into X-ray photons. Electrons having maximum kinetic energy create the shortest wavelength X-ray photons. Calculate the shortest wavelength of X-ray photons emitted from an X-ray machine operating at 120 kV.

wavelength = ...................................................... m **[3]**

**(d)** X-ray photons interact with matter. One of the interaction mechanisms of the X-ray photons with atoms is known as the **photoelectric effect**. State another interaction mechanism. Describe what happens to the X-ray photon interacting with a single atom using the mechanism you have stated.

...................................................................................................................................................

...................................................................................................................................................

............................................................................................................................................. **[2]**

**[Total: 9]**

10)

**(a)** In the treatment of patients, explain what is meant by a non-invasive technique. State one of its advantages.

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[2]**

**(b)** Explain what is meant by a medical tracer. Name a medical tracer commonly used to diagnose the function of organs.

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[2]**

**(c)** The main components of a gamma camera are the collimator, scintillator, photomultiplier tubes and the computer. Describe the function of each of these components.

*In your answer, you must make clear how one of these components governs the sharpness of the image.*

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[5]**

**(d)** Fig. 8.1 shows an ultrasound transducer placed above an artery.

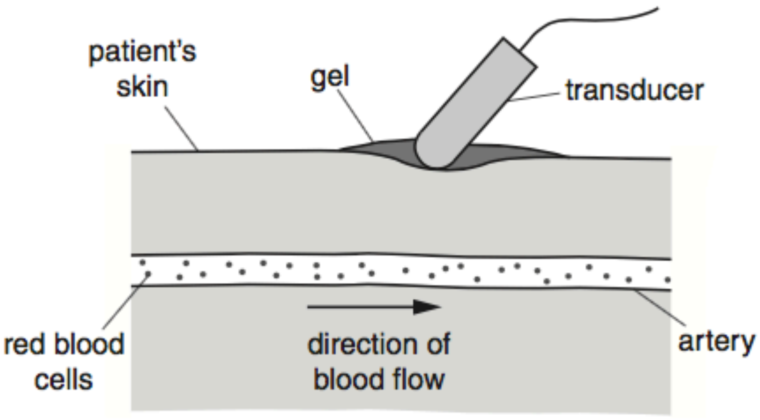


**Fig. 8.1**

**(i)** The speed of ultrasound in blood is $1500\,\text{m}\,\text{s}^{-1}$. Calculate the wavelength of the ultrasound of frequency $2.0 \times 10^6$ Hz.

wavelength = ........................................................ m **[2]**

**(ii)** Describe how the ultrasound is used to determine the speed of the blood in the artery.

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

.................................................................................................................... **[3]**

**[Total: 14]**

11)

**(a)** State two properties of X-rays.

1. ......................................................................................................................

......................................................................................................................

2. ......................................................................................................................

...................................................................................................................... **[2]**

**(b)** Explain what is meant by the *Compton effect*.

......................................................................................................................

......................................................................................................................

......................................................................................................................

...................................................................................................................... **[2]**

**(c)** The intensity $I$ of a collimated beam of X-rays decreases exponentially with thickness $x$ of the material through which the beam passes according to the equation $I = I_0 e^{-\mu x}$. The attenuation (absorption) coefficient $\mu$ depends on the material.

**(i)** State what $I_0$ represents in this equation.

...................................................................................................................... **[1]**

**(ii)** Bone has an attenuation coefficient of 3.3 $cm^{-1}$. Calculate the thickness in cm of bone that will reduce the X-ray intensity by half.

thickness = ..................................................... cm **[3]**

**(d)** Explain the purpose of using a contrast medium such as barium when taking X-ray images of the body.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[2]**

**[Total: 10]**

12)

**(a)** State one reason for using non-invasive techniques in medical diagnosis.

.......................................................................................................................................

....................................................................................................................................... **[1]**

**(b)** Describe the use of medical tracers to diagnose the condition of organs.

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[2]**

**(c)** Describe the principles of positron emission tomography (PET).

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

.......................................................................................................................................

....................................................................................................................................... **[5]**

**[Total: 8]**

13)

**(a)** Describe the principles of ultrasound scanning.

*In your answer, you should make clear how the steps in the process are sequenced.*

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

.............................................................................................................................................. **[4]**

**(b)** Explain the difference between an ultrasound A-scan and B-scan.

..................................................................................................................................................

..................................................................................................................................................

..................................................................................................................................................

.............................................................................................................................................. **[1]**

**[Total: 5]**

14)

**(a)** State and describe **one** way in which X-ray photons interact with matter.

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

................................................................................................................................... **[2]**

**(b)** The intensity of a collimated beam of X-rays is reduced to 10% of its initial value after passing through 3.0 mm of soft tissue. Calculate the thickness of soft tissue that reduces the intensity to 50% of its initial value.

thickness = ................................................ mm **[3]**

**(c)** X-rays are used to image internal body structures.

**(i)** Explain how image intensifiers are used to improve the quality of the X-ray image.

*In your answer, you should explain clearly the process involved which makes the image brighter.*

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

................................................................................................................................... **[3]**

**(ii)** Explain how contrast media are used to improve the quality of the X-ray image.

...................................................................................................................................

...................................................................................................................................

...................................................................................................................................

................................................................................................................................... **[2]**

**[Total: 10]**

15)

**(a)** Describe briefly how X-rays are produced in an X-ray tube.

.............................................................................................................................................

.............................................................................................................................................

............................................................................................................................................. **[2]**

**(b)** Describe the Compton Effect in terms of an X-ray photon.

.............................................................................................................................................

.............................................................................................................................................

.............................................................................................................................................

............................................................................................................................................. **[2]**

**(c)** A beam of X-rays of intensity $3.0 \times 10^9$ W m$^{-2}$ is used to target a tumour in a patient. The tumour is situated at a depth of 1.7 cm in soft tissue. The attenuation (absorption) coefficient μ of soft-tissues is 6.5 cm$^{-1}$.

**(i)** Show that the intensity of the X-rays at the tumour is about $5 \times 10^4$ W m$^{-2}$.

**[2]**

**(ii)** The cross-sectional area of the X-ray beam at the tumour is 5 mm$^2$. The energy required to destroy the malignant cells of the tumour is 200 J. The tumour absorbs 10% of the energy from the X-rays. Calculate the total exposure time required to destroy the tumour.

time = ...................................................... s **[3]**

**(d)** Describe the operation of a computerised axial tomography (CAT) scanner. State **one** of the advantages of a CAT scan image over a conventional X-ray image.

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

.................................................................................................................................... **[5]**

**[Total: 14]**