2024 H2 Biology Prelim Paper 3 Answer

1 Thyroid hormones are produced and released by the thyroid gland. In humans, the thyroid gland is found in the neck below the Adam's apple. It is lined with thyroid follicular cells, also called thyrocytes, that surround a lumen.

Fig. 1.1 shows the thyroid follicular cells.

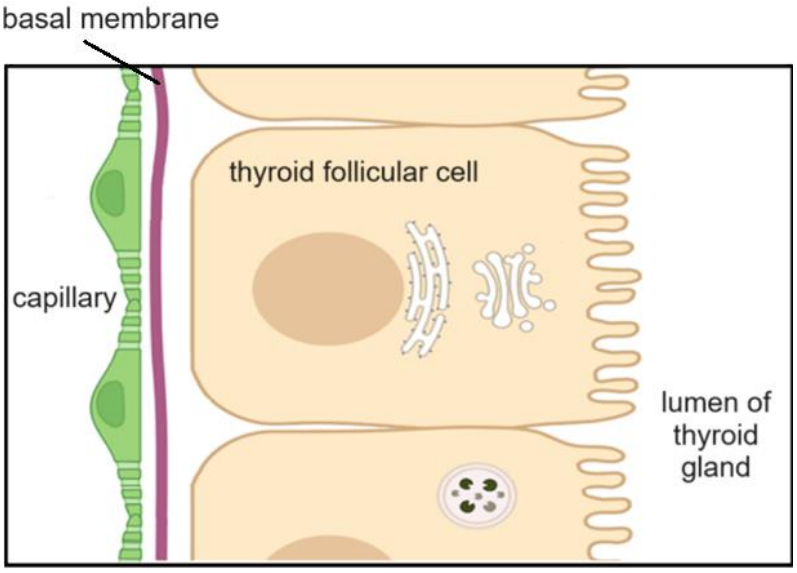

Fig. 1.1

Unlike most hormones with specific target cells or tissues, the thyroid hormones act on nearly every cell in the body and are important in regulating the basal metabolic rate of the body. They regulate the metabolism of proteins, fat and carbohydrates in cells, affecting protein synthesis and cellular respiration. They are also involved in the control of heat generation in the body and are essential for proper cell development and differentiation.

There are two types of thyroid hormones, namely triiodothyronine (T_3) and thyroxine (T_4). Their structures differ by the number of iodine present.

Fig. 1.2 shows the structure of T_3 and T_4.

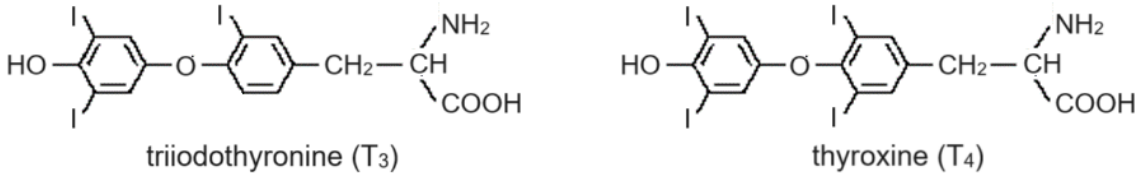

Fig. 1.2

(a) With reference to Fig. 1.1 and 1.2,

(i) suggest how thyroid hormones are able to act on nearly every cell in the body. [1]

- Thyroid hormones are **secreted into the capillaries** and **carried throughout the body by the circulatory system / via the blood**;

(ii) compare the structure of thyroid hormones to an amino acid. [2]

Similarity
- Both thyroid hormones and amino acid have a **central carbon** bonded to a **hydrogen atom**, an **amino group**, a **carboxyl group** and a variable **R group**;
(accept mention of just 1 of the groups)

Difference
- Thyroid hormones contain **iodine atoms** but not amino acids;

(b) The release of thyroid hormones from the thyroid gland is regulated by other hormones released from the brain. Neurones in the hypothalamus in the brain release thyrotropin-releasing hormone (TRH), which stimulates the release of thyroid-stimulating hormone (TSH) from cells in the anterior pituitary. TSH then stimulates the release of T_3 and T_4 from the thyroid gland.

Fig. 1.3 shows the relationship between different tissues in the control of the release of thyroid hormones.

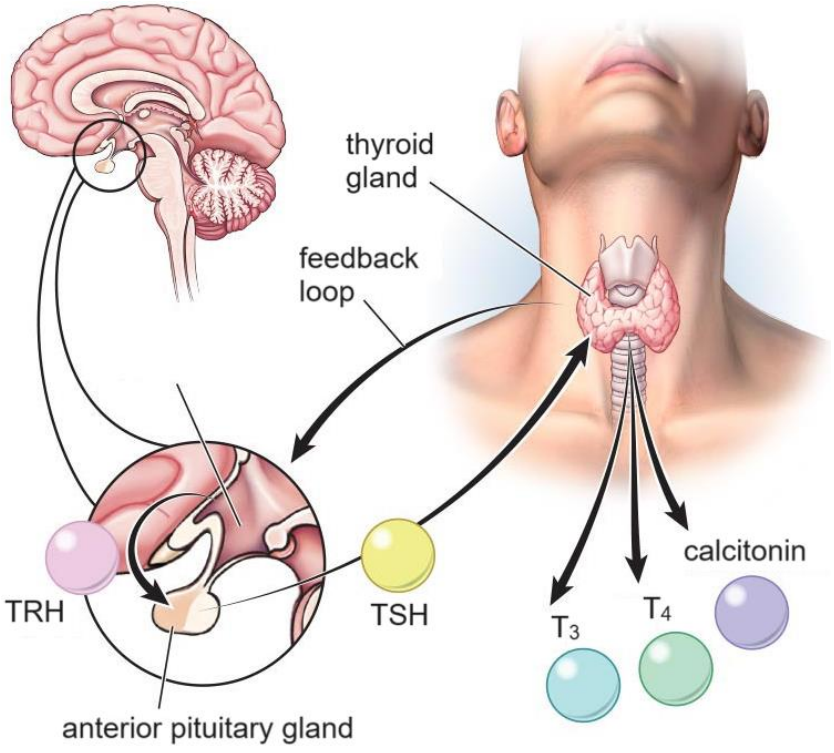

Fig. 1.3

Research was conducted to study the effect of TSH on the release of thyroid hormones from the thyroid gland. In this research, pluripotent stem cells were induced to differentiate into a culture of thyroid follicular cells. TSH was then introduced into the culture medium

of this cell culture, and the amount of T_3 and T_4 released into the culture medium was measured for a period of one week.

The result of this experiment is shown in Fig. 1.4.

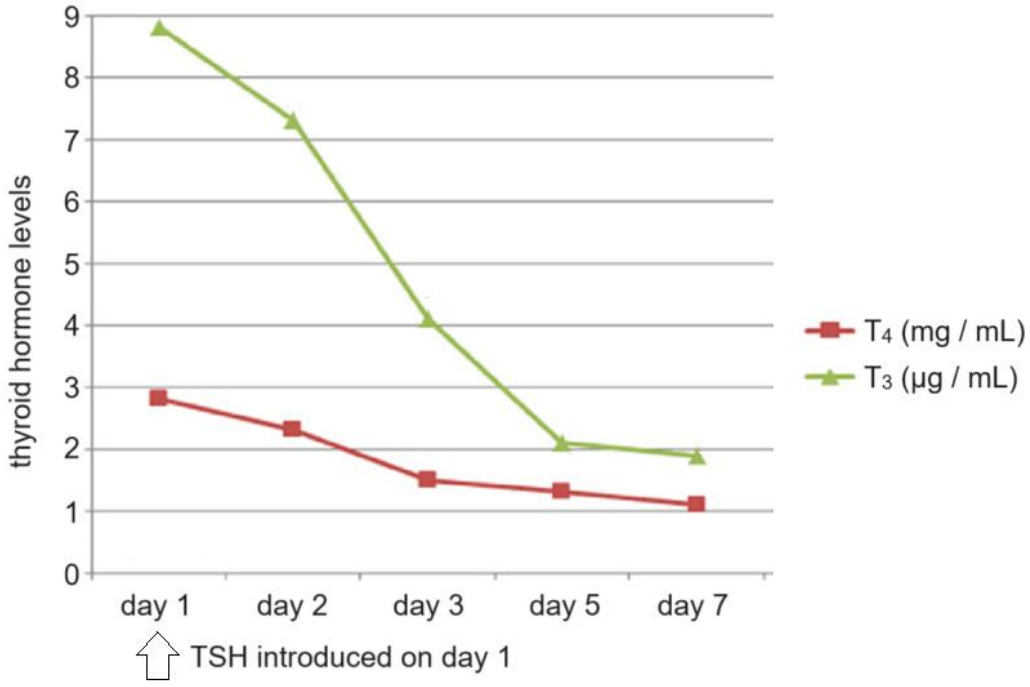

Fig. 1.4

With reference to Fig. 1.4,

(i) compare the changes in the levels of T_3 and T_4 in the cell culture medium during the week. [2]

Similarity
- The levels of both T_3 and T_4 **decreased** in general;

Difference
- The **starting level of T_3 was lower** at 8.8 µg/mL than that of T_3 at 2.8 mg/mL;
- The **level of T_3 decreases at a faster rate**, from 8.8 µg/mL in day 1 to 1.8 µg/mL in day 7, compared to that of T_4 from 2.8 mg/mL in day 1 to 1.2 µg/mL in day 7;

(ii) contrast the release of thyroid hormones with the release of antibodies. [1]

- Thyroid hormones were released on the **same day that TSH was introduced**, while antibodies are released **a few days after an antigen is introduced**;

(c) The research continued and managed to discover the signalling pathways involved in the stimulation of the thyroid gland by TSH. The action of TSH on the thyroid follicular cells in the thyroid gland is shown in Fig. 1.5.

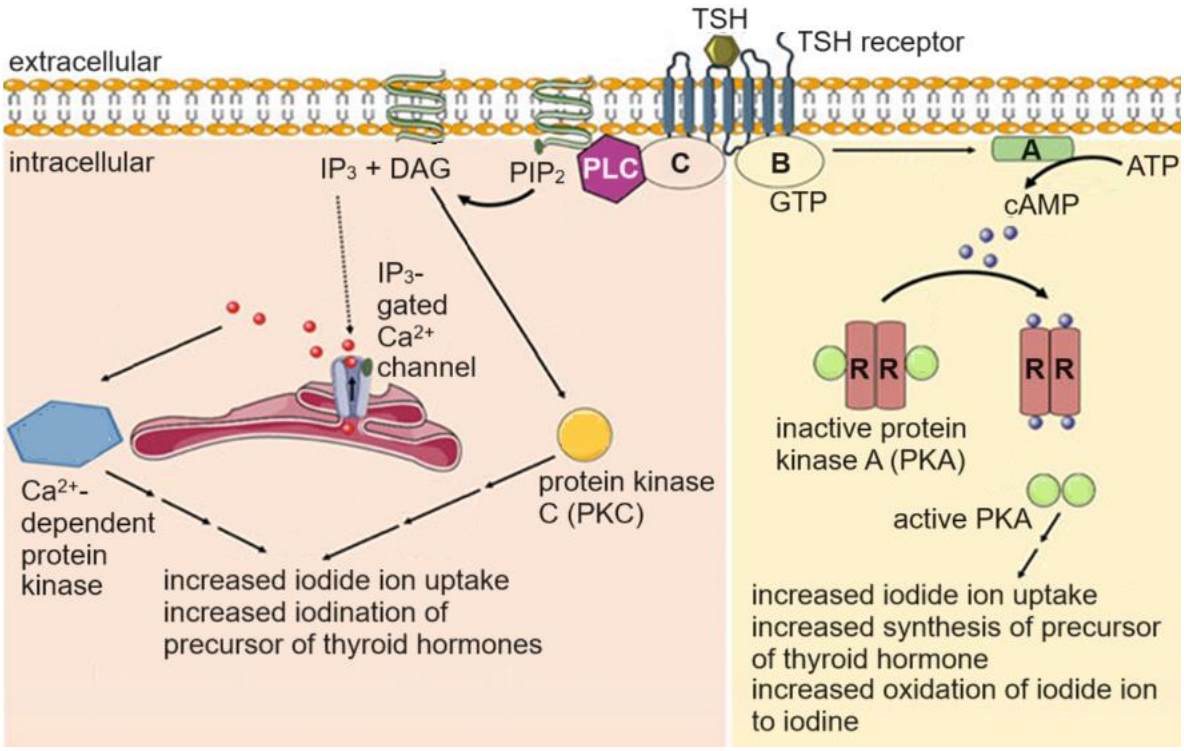

Fig. 1.5

(i) Identify the proteins labelled **A** and **B**. [2]

- A: adenyl cyclase;
- B: G protein;

(ii) Explain the significance of protein **A** in TSH signalling. [3]

- Upon activation by the binding of the G protein, **adenyl cyclase catalyses the conversion of ATP to cAMP**, resulting in an increase of cAMP concentration in the cytoplasm;
- (4 molecules of) **cAMP bind to protein R** (dimer), resulting in the **release of active PKA** (dimer) from protein R (dimer);
- **Active PKA catalyses the phosphorylation of other kinases / relay proteins**, triggering the **phosphorylation cascade / signal transduction pathways** that result in cellular responses in the thyroid follicular cells for the synthesis and secretion of thyroid hormones;

(iii) Ca^{2+} ions are released from an organelle in the thyroid follicular cell when the cell is stimulated by TSH.

Describe how the structure of this organelle allows its roles in TSH signalling. [3]

- Ref. to the organelle as the **smooth endoplasmic reticulum** (sER);
- Lumen surrounded by **membrane impermeable to Ca^{2+}** allows **storage of high concentration of Ca^{2+} ions** (higher concentration than cytoplasm) in the lumen of the sER;
- Presence of **IP_3-gated Ca^{2+} channels** on the membrane of sER, which open when bound by IP_3, allows the **facilitated diffusion of Ca^{2+} from the lumen of sER into the cytoplasm**;

- **Ca^{2+} bind to and activate Ca^{2+}-dependent protein kinase** to catalyse the phosphorylation of other kinases / relay proteins, **triggering the phosphorylation cascade / signal transduction pathways** that result in cellular responses in the thyroid follicular cells for the synthesis and secretion of thyroid hormones;

(d) Beside the action of TRH and TSH, another regulatory mechanism of thyroid hormones is via the supply of iodine, an important component of thyroid hormones.

Most dietary iodine is reduced to iodide ions before absorption by the small intestine. The iodide ions are transported to the thyroid gland via the circulatory system and accumulated in thyroid follicular cells.

Fig. 1.6 shows the uptake of iodide ions by a thyroid follicular cell.

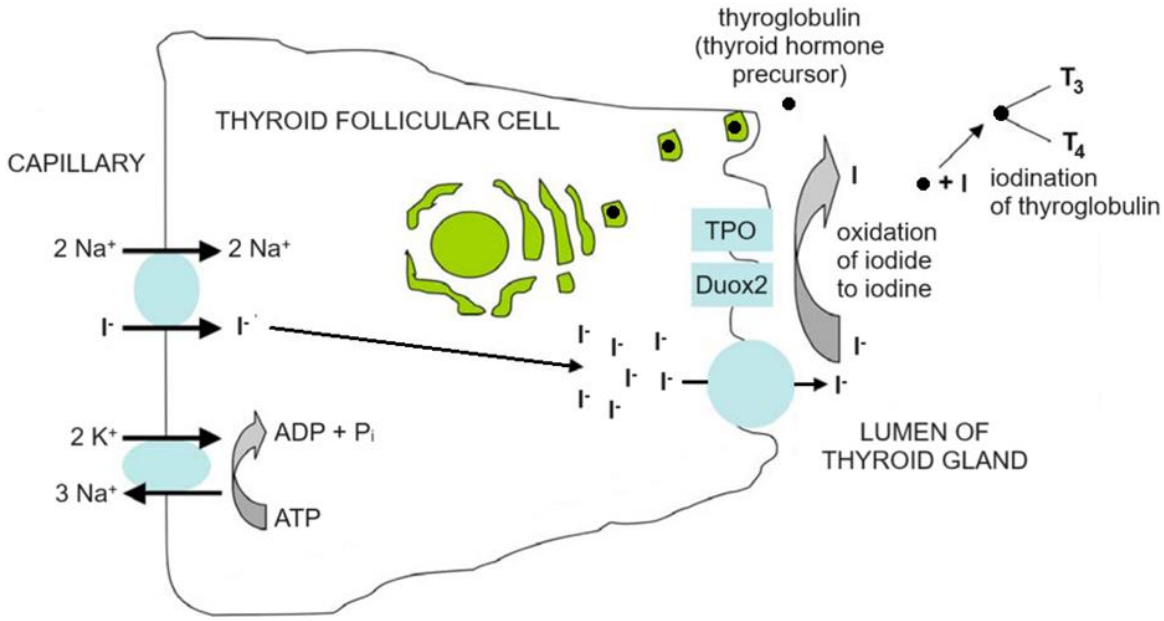

Fig. 1.6

With reference to Fig. 1.6 and your knowledge on transport across membrane,

(i) calculate the number of ATP required in the uptake of 10 mol of iodide ions into the thyroid follicular cell. Leave your answer to 3 significant figures.

Show your working in the space provided. [1]

- 20 / 3 = 6.67 mol of ATP (3 s.f.);

(ii) explain the need for transport proteins in the uptake of iodide ions into the thyroid follicular cell. [4]

Need for hydrophilic environment

- Iodide ions are **charged and polar** / **hydrophilic**, and cannot cross the cell surface membrane due to the **hydrophobic core** of the cell surface membrane;

- The iodide ion transport protein provides a **hydrophilic channel** / **binding site** to **shield the iodide ions** from the hydrophobic core to bring them into the cell;

Need for Na^+ gradient

- **Concentration of the iodide ions is higher in the cytoplasm** inside the cell than in the capillary / The iodide ions is **transported into the cell against its concentration gradient**;
- The iodide ions are transported into the cell **together with Na^+**, which enters the cell **down its concentration gradient**;
- The Na^+-K^+ pump **transports Na^+ out of the cell into the capillary against its concentration gradient**, with energy from ATP hydrolysis, to set up a **high Na^+ concentration in the capillary**;

(iii) state **two** differences between the transport of iodide ions and thyroglobulin into the lumen of the thyroid gland. [2]

feature of comparison	transport of iodide ions into thyroid gland lumen	transport of thyroglobulin into thyroid gland lumen
mode of transport	active transport	exocytosis
involvement of transport protein	transport protein involved	transport protein not involved
involvement of vesicles	iodide ions not packaged into vesicles	thyroglobulin packaged into secretory vesicles

(e) Thyroid hormones, unlike most protein hormones, are transported into target cells and bind to intracellular receptors known as thyroid hormone receptors (TRs). TRs often form heterodimers with retinoic X receptor (RXR) and act as a transcription factor for a wide variety of genes. The dimer binds to a thyroid hormone response element (TRE) on the DNA and recruits co-repressors to repress gene expression.

Fig. 1.7 shows the action of thyroid hormone in the target cell.

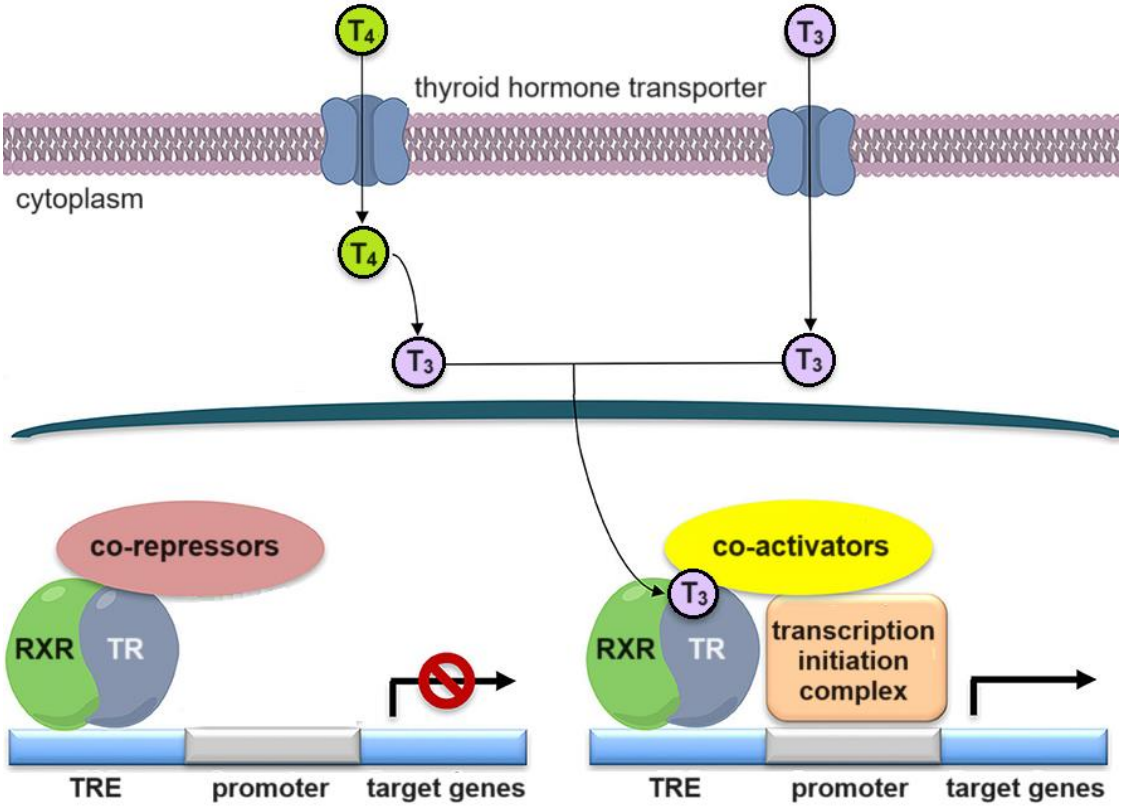

Fig. 1.7

(i) Briefly outline how T_4 is converted to T_3 in the cytoplasm. [1]

- Enzymatic **removal of an iodide ion**;

(ii) An example of co-repressors is histone deacetylase.

Explain how histone deacetylase represses gene expression. [3]

- **Removes acetyl groups** from free **lysine residues at N-terminus of histones**;
- This **restores the positive charge of histones**, thus **increasing the ionic attraction between histones and DNA**;
- DNA is **more tightly coiled** around histones / Chromatin is **more tightly coiled**;
- This **reduces the accessibility of general transcription factors and RNA polymerase to the promoter**, thus **preventing formation of transcription initiation complex** at the promoter;

(iii) Outline how T_3 switches on gene expression after entering the target cell. [4]

- **T_3 enters the nucleus** from the cytoplasm via **nuclear pores**;
- **T_3 binds to TR** of the RXR-TR heterodimer at the TRE;
- The T_3-bound RXR-TR heterodimer **recruits co-activators** instead of co-repressors;
- This allows the **formation of transcription initiation complex at the promoter**, which allows transcription of the gene;

(iv) The thyroid hormones are transported into target cells via active transport.

Suggest an advantage in the mode of transport of thyroid hormones. [1]

- Transport of thyroid hormones into target cells does not depend on concentration gradient;

2 In the past, dieticians often advocated a diet low on fats to lose weight. Nowadays, many people are praising the benefits of the ketogenic diet that is high in fat intake but low on carbohydrate intake. Health benefits include weight loss and lowering one's risk for certain diseases.

Fig. 2.1 shows a comparison of the weight loss achieved with low-carbohydrate or low-fat diets over a two-year period.

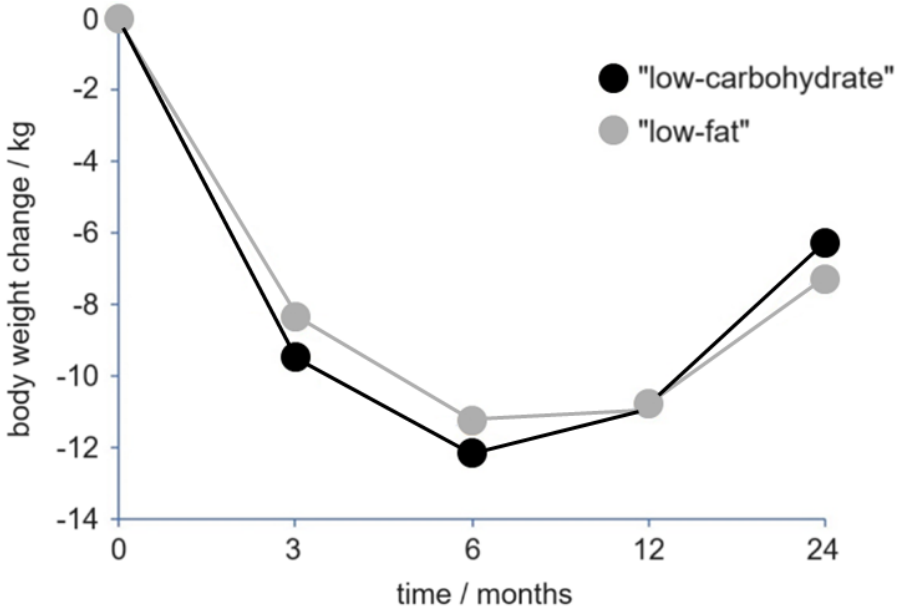

Fig. 2.1

(a) With reference to Fig. 2.1, compare the impact of weight loss of the low-carbohydrate and low-fat diets over a two-year period. [4]

Similarities (any two)
- Both diets can allow a weight loss of 6kg or more over 2 years;
- Both diets show the highest weight loss in 6 months;
- Both diets show a weight gain (rebound) after 6 months;
- Both diets show 11kg weight loss after 12 months;

Differences (any two)
- The low fat diet shows greater weight loss of ~8kg compared to low carb diet with ~7 kg after 12 months;
- The greatest weight loss after 6 months was at 12 kg was achieved with the low carb diet, compared to low fat diet at 11.5 / 11kg;
- Low carb diet was generally more effective at weight loss for up to 12 months, after which, a low fat diet works better;

(b) Fig. 2.2 shows the major pathways in insulin receptor signalling.

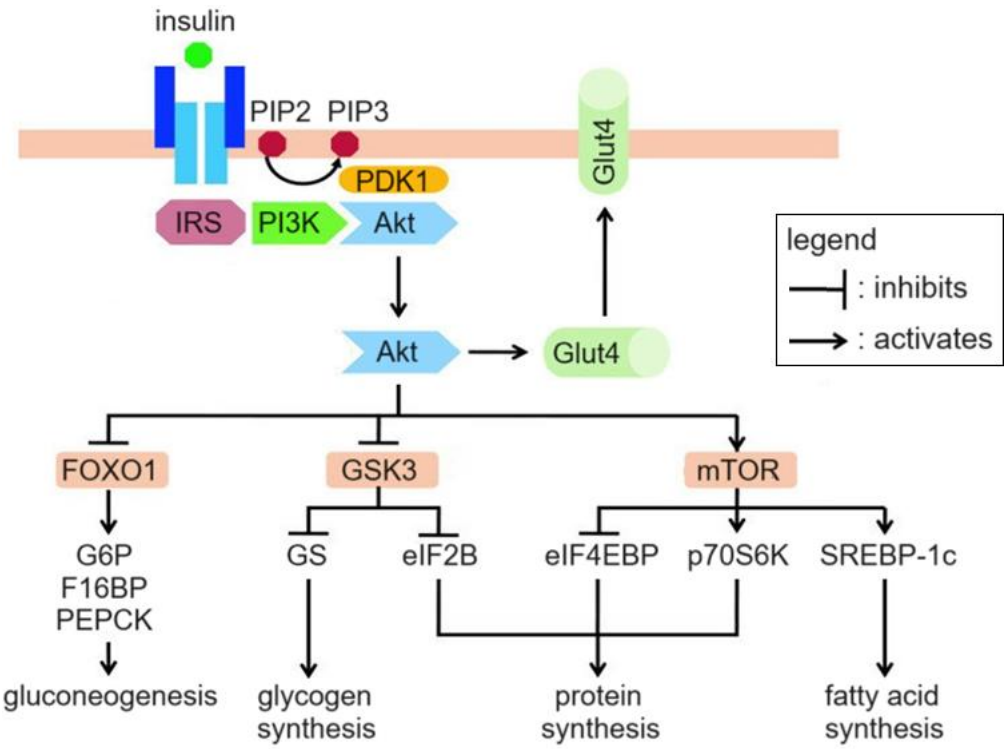

Fig. 2.2

Using Fig. 2.2 and your knowledge on glucose regulation in the body, suggest how a low-carbohydrate diet can help to facilitate weight loss. [3]

- In carbohydrate-rich diets, the insulin secreted by the pancreas allows fat cells to capture the sugars released into the blood and to turn them into fat for future use;
- Insulin inhibits gluconeogenesis but stimulates glycogen, protein and fatty acid synthesis;
- These actions of insulin ensure that fat tissue not only accumulates excess calories, but that these calories cannot even be used to support the body's energy needs;

(c) The RQ value corresponds to the relative amount of CO_2 and O_2 involved in respiration and can provide information about the type(s) of substrate the body is using for energy.

Tripalmitin is a triglyceride. The chemical equation for aerobic respiration of tripalmitin is:

$$2\ C_{51}H_{98}O_6 + 145\ O_2 \longrightarrow 102\ CO_2 + 98\ H_2O$$

The formula for calculating the RQ value is:

$$RQ = \frac{\text{volume of } CO_2 \text{ liberated}}{\text{volume of } O_2 \text{ consumed}}$$

(i) Calculate the RQ value for tripalmitin. Give your answers to 2 decimal places.

Show your working in the space provided below. [1]

- 102 / 145 = 0.70 (2 d.p.);

(ii) Explain why the usual RQ value for respiration in humans is between 0.7 and 1.0. [1]

- RQ values will add to 1.0 if complete breakdown of glucose is achieved, different tissues can utilise other forms of substrates aerobically;

3 Li-Fraumeni syndrome (LFS) is a rare, inherited genetic disorder that significantly increases the risk of developing various types of cancer, often at a young age, including breast cancer, sarcomas (cancers of connective tissues), brain tumours, and adrenocortical carcinoma (a rare cancer of the adrenal glands).

Fig. 3.1 shows the estimated probability of individuals with LFS being diagnosed with cancer in their lifetime when compared to normal individuals.

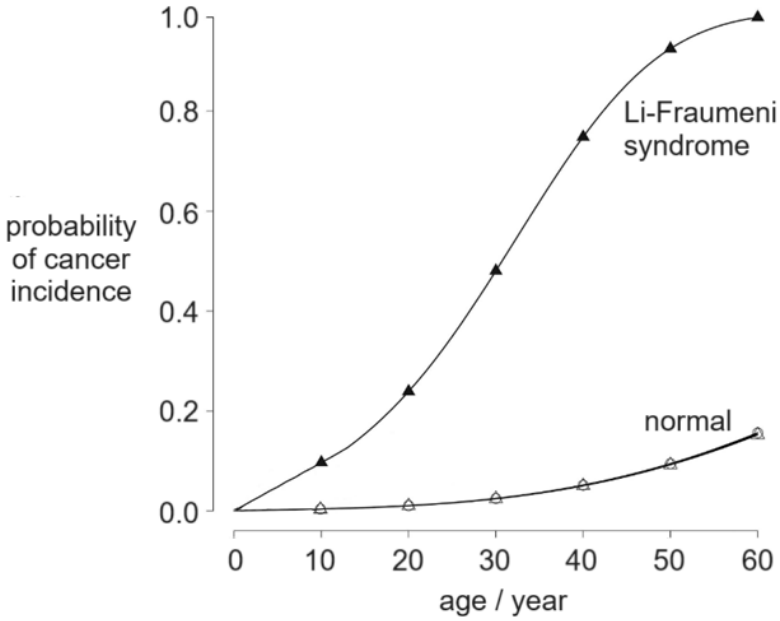

Fig. 3.1

Many individuals with LFS have a family history of multiple cancers, sometimes spanning several generations. This pattern of cancer occurrence helps in identifying the syndrome.

Research has shown that the disorder arises due to a mutation in the *p53* tumour suppressor gene occurring in germline cells.

(a) Give the evidence that supports the *p53* gene mutation occurring in germline cells and explain your answer. [1]

- Many individuals with LFS have a family history of multiple cancers, which may span several generations – Germline cells are involved in the formation of gametes, hence involved in the passing down of genetic material, including the mutation to their progeny in the process of sexual reproduction; (if somatic, won't be passed down);

(b) (i) With reference to Fig. 3.1, describe how Li-Fraumeni syndrome affects an individual's probability of developing cancer. [2]

1. Individual affected by LFS has a **higher probability** of developing cancer when compared to normal individuals at all ages;

2. [QV] birth till 60 years of age, the probability of developing cancer in Li-Fraumeni individuals increases from 0.0 to 1.0, while the probability in normal individuals increases from 0.0 to 0.15 only;

(ii) Using your knowledge on cancer development, explain your answer in **(b)(i)**. [4]

1. Idea that mutation occurs in the other normal TP53 allele / **loss of heterozygosity** resulting in **loss of function mutation** in TP53 gene;
2. Leads to non-functional p53 protein which is **unable to halt cell cycle**, **activate DNA repair**, **induce apoptosis** (at least 2 out 3);
3. Ref. to cancer development as **multistep process** involving **accumulation of mutations** over time;
4. Including **gain of function mutation** in at least one **proto-oncogenes** and loss of function in other tumour suppressor genes;
5. Leads to uncontrolled cell division – cancer;
6. Idea of metastasis and angiogenesis;

(c) Young people with LFS can lead fulfilling and relatively normal lives, but their experiences may be different from those of their peers due to the heightened risk of cancer and the necessary precautions. They often undergo regular screenings and check-ups to detect any signs of cancer early. This can mean frequent medical appointments, imaging tests, and sometimes preventive treatments.

Coping with the risks associated with LFS and the possibility of cancer can be emotionally challenging for young people with LFS. Nonetheless, these youths should stay away from less healthy coping mechanisms, such as vaping.

E-cigarette vapor contains a variety of chemicals, some of which are known to be harmful. For instance:

- Nicotine: While nicotine itself is not classified as a carcinogen, it can promote tumour growth and progression by influencing cell proliferation and survival.
- Formaldehyde: It is a known carcinogen and can be found in some e-cigarette liquids, particularly when heated to high temperatures.
- Acrolein: Another harmful compound, acrolein can irritate tissues and contribute to inflammation and oxidative stress.

Suggest how acrolein may increase the risk of cancer development. [1]

1. Oxidative stress can increase the likelihood of DNA mutations / damage, which are a key factor in cancer development;
2. Chronic inflammation may damage cells and overstimulate cell division (increase rate of mitosis to replace damaged cells);

(d) Researchers explored a technique known as gene therapy to treat patients with LFS. The steps are shown in Fig. 3.2.

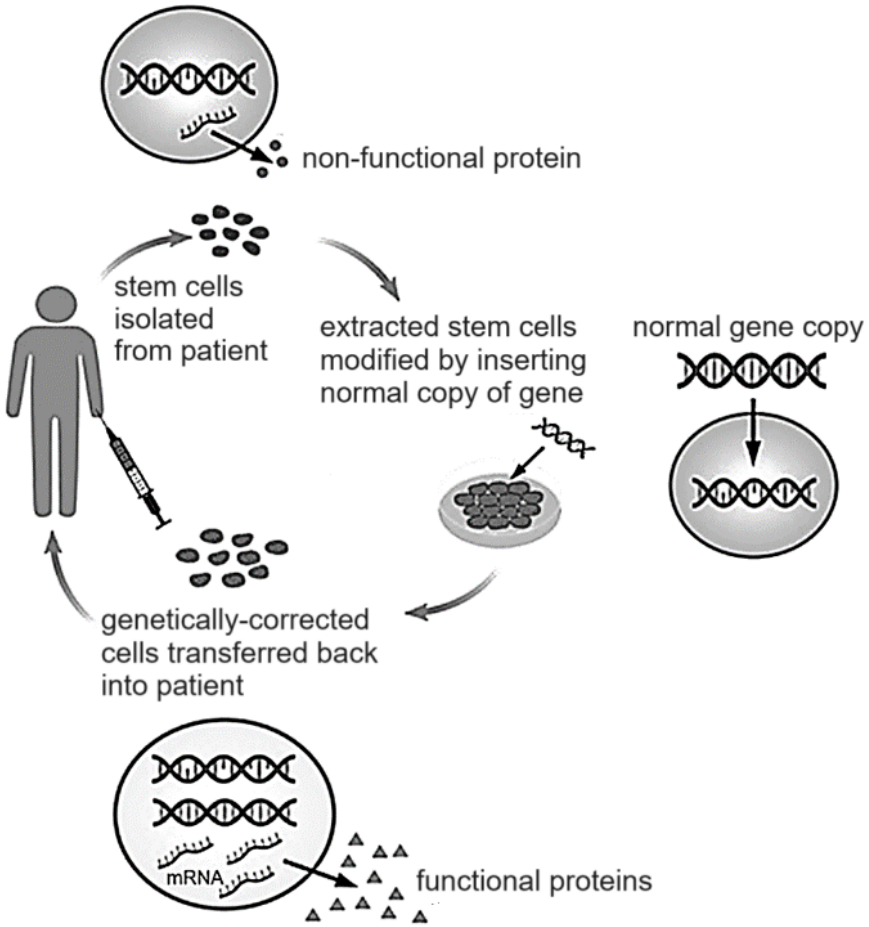

Fig. 3.2

Identify the type of stem cells extracted from the patient and describe the features of this stem cell. [3]

1. Adult stem cells / Multipotent stem cells;
2. Stem cells are **unspecialised** cells which are able to differentiate into a **limited range** of cell types / several cell types under certain conditions;
3. Stem cells are capable of **dividing and renewing themselves** / **self-renewal** for long periods via **mitotic divisions**;

4 Glucagon is an important protein found in most vertebrates. It functions in the regulation of glucose metabolism.

(a) Describe the roles of named RNA molecules in the synthesis of glucagon. [15]

(1) mRNA
- Mature mRNA serves as template for translation to synthesise glucagon;
- mRNA is read in triplets 5' to 3';
- Sequence of triplet codons codes for amino acid sequence of glucagon polypeptide;
- Translation begins at the start codon AUG and is terminated at the stop codon UAG, UGA, UAA;

(2) rRNA
- rRNA is a component of ribosomes together with ribosomal proteins;
- rRNA at the mRNA binding site of the small ribosomal subunit binds to 5' UTR of mature mRNA via complementary base pairing during translation initiation;
- rRNA of the large ribosomal subunit forms peptidyl transferase;
- Which catalyses the formation of peptide bonds between the amino acid in the A site and the growing polypeptide in the P site;

(3) tRNA
- tRNA is added with specific amino acid by aminoacyl-tRNA synthetase;
- tRNA brings the correct amino acid to the A site of the ribosome;
- Anticodon of tRNA forms complementary base pairing with codons of mRNA at the A site;

(4) snRNA
- snRNA in snRNPs binds to splice sites of introns via complementary base pairing to position snRNPs at the ends of introns;
- snRNPs complex together to form spliceosome;
- Causing the introns to be looped into lariats, bringing the exons on both sides of the introns close together;
- Spliceosomes excide introns and splice exons together during post-transcriptional modifications;

- QWC: At least one point from at least two types of RNA;

(b) Discuss the advantages and disadvantages in the use of glucagon to determine phylogeny between species. [10]

(1) How glucagon is used to determine phylogeny
- Isolate glucagon from different species and compare the amino acid sequences;
- Fewer differences, more closely related species with a more recent common ancestor;

(2) Advantages
- Quantitative, objective, unambiguous comparison of the number of differences in the glucagon amino acid sequence in different species;
- Each amino acid position serves as a point of comparison between species, giving rise to many points of comparison / extensive scope of comparison;
- Able to obtain glucagon amino acid sequence in different species from online databases;
- Glucagon is found in most vertebrates, can be used for comparison between most vertebrates;

- Glucagon is a homologous protein in most vertebrates, avoiding the pitfall of analogous structures that do not show phylogeny;

(3) Disadvantages
- Cannot be used to compare with organisms that do not make use of glucagon e.g. bacteria, plants, other non-vertebrates, etc.;
- Ref. to degeneracy of the genetic code, giving rise to silent mutations in the glucagon gene that do not result in differences in glucagon amino acid sequences between species;
- Ref. to mutations in introns in glucagon gene which are excised from the mature mRNA, do not result in differences in glucagon amino acid sequences between species ;

- QWC: At least one point from both (2) and (3);

5 The immune system consists of a complex network of organs, cells and proteins. It plays an important role in defending the body against infections by pathogens, as well as cancer.

(a) Describe the roles of named proteins in the activation of the humoral immune response. [15]

- Ref. to humoral immune response as part of adaptive immune response involving antibodies;

(1) Antigen presentation
- Ref. to dendritic cells, macrophages, monocytes;
- Receptors on antigen presenting cells recognise broad range of antigens on different pathogens;
- Trigger phagocytosis of pathogens, engulfing the pathogens and placing them in phagosomes;

- Ref. to fusion of phagosomes with lysosomes;
- Hydrolytic enzymes in lysosomes digest the pathogens and the antigens of the pathogens;

- MHC class II proteins bind to antigen peptides;
- MHC II-antigen complex inserted into cell surface membrane to present the digested antigen peptides on the cell surface;

(2) Activation of T helper cells;
- T cell receptors of naïve helper T cells bind to specific antigens presented on antigen presenting cells, aided by CD4 receptors;
- Helper T cells with specific T cell receptors for the antigens are activated to release cytokines;

(3) Activation of B cells;
- B cell receptors of naïve B cells bind to specific antigens via complementary shape of the antigen binding sites on the receptors;
- Aided by cytokines released by helper T cells, B cells with specific B cell receptors for the antigens are activated to undergo clonal expansion and differentiation into plasma cells;
- Plasma cells synthesise and secrete antibodies specific for the antigens, thus activating the humoral immune response;
- Ref. to the antibodies binding to specific antigens on the pathogens, resulting in neutralisation, opsonisation, agglutination, etc.;

- QWC: At least one point from at least two parts;

(b) Explain how viral infections may contribute to the occurrence of cancer. [10]

(1) Insertion of viral genome
- Ref. to retroviruses e.g. HIV;
- Viral DNA is inserted into genome of host cell;

- Insertion of viral DNA into tumour suppressor genes;
- Disrupt gene sequence, resulting in non-functional gene product;
- Unable to halt cell cycle or trigger apoptosis;

- Insertion of viral DNA near proto-oncogenes;
- Viral control elements increase expression of proto-oncogenes;
- Overstimulation of cell cycle;

(2) Impairment of immune system
- Ref. to immune system being overloaded;
- Unable to detect or mount response to cancerous cells;

- HIV causes the death of helper T cells;
- Unable to trigger adaptive immune responses against cancerous cells;

- QWC: At least one point from both parts;