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9.2 Transport in the Phloem of Plants

IB Biology - Revision Notes

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9.2.1 Translocation in Plants

Translocation

- Translocation is the biological term used to describe the **transport of organic solutes** in the **phloem tissue**
  - The liquid that is being transported within the phloem can be referred to as **phloem sap**
  - This phloem sap consists of **sugars** in the form of sucrose, along with **water** and other dissolved substances such as **amino acids**
    - These dissolved substances are sometimes referred to as assimilates
- Translocation within phloem tissue transports these organic compounds from regions known as **'sources'** to regions known as **'sinks'**

Sources and Sinks

- Sources are the regions of plants in which **organic solutes originate**; they can include
  - **Mature green leaves** and **green stems**
    - **Photosynthesis** in these regions **produces glucose** which is converted into sucrose before being transported
  - **Storage organs**, e.g. tubers and tap roots, unloading their stored substances at the beginning of a growth period
  - Food stores in **seeds which are germinating**
- Sinks are the regions of plants where **organic compounds are required** for growth; they can include
  - Meristems that are actively dividing
  - **Roots that are growing** or actively **taking up mineral ions**
  - **Young leaves** in bud
  - Any part of the plant where **organic compounds are being stored** eg. developing seeds, fruits, or storage organs
- Note that **sources can become sinks and vice versa**, depending on the time of year and the processes taking place inside the plant

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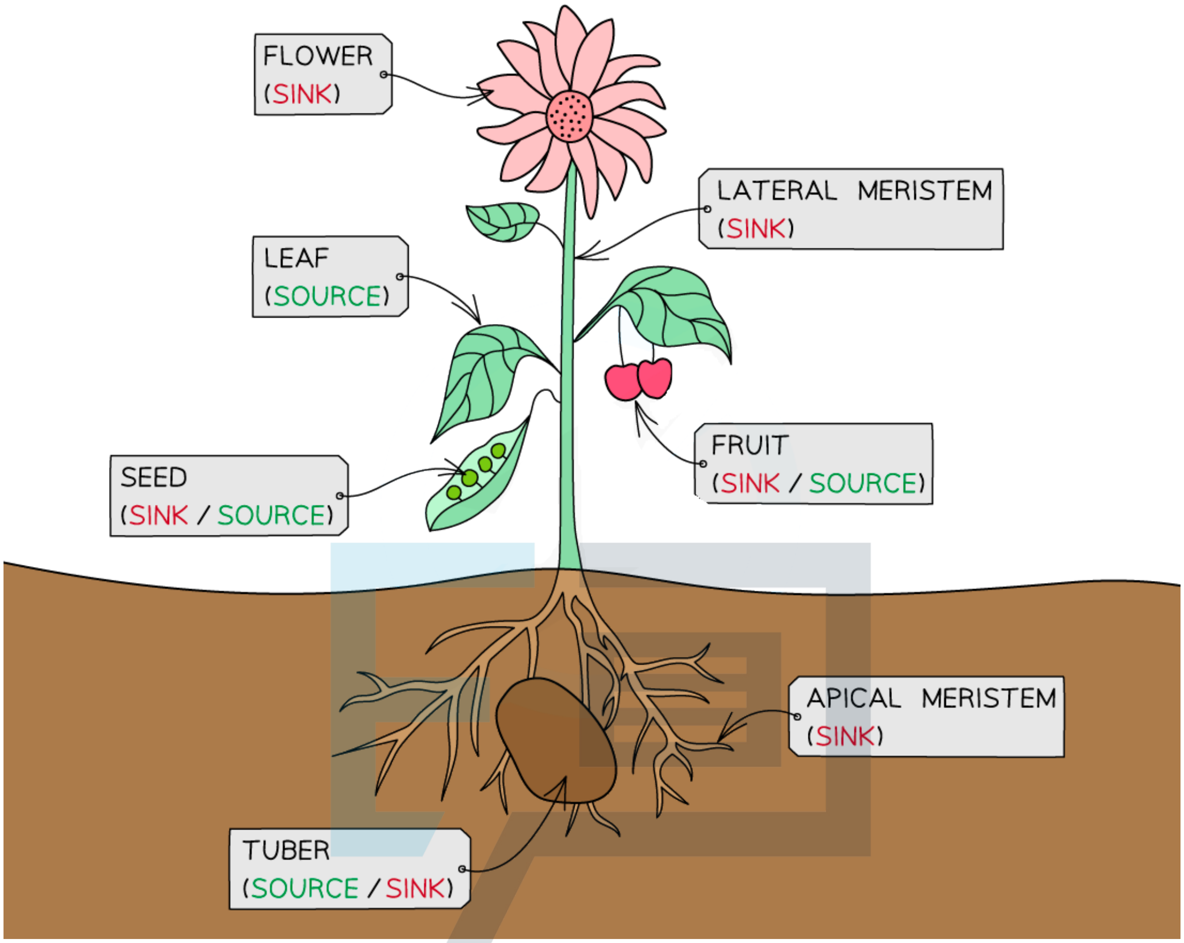

Organic compounds are moved through a plant by the process of translocation. They are moved from source(s) to sink(s).

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Translocation is an active process

- The **loading** and **unloading** of sucrose and other organic compounds from the **source to the phloem**, and from the **phloem to the sink** is an **active process**, meaning that it requires energy in the form of ATP
- A summary of the process is
  - **Active transport** is used to **load organic compounds** into the phloem at the source
  - The high concentrations of solutes in the phloem at the source cause **water to move into the phloem** vessels by osmosis
  - This results in a **raised hydrostatic pressure**, which causes the **contents of the phloem to flow towards sinks**
    - Hydrostatic pressure refers to the pressure exerted by a fluid on the walls of its container; in this case the walls of the phloem

> **Exam Tip**
>
> Remember that direction of movement in the phloem is determined by the locations of the source and the sink, so can be either upward or downward.

Phloem Sieve Tubes

- The function of phloem tissue in a plant is to **transport organic compounds**, particularly sucrose, **from sources**, e.g. leaves, **to sinks**, e.g. roots
  - The transport of these compounds can occur both **up or down the plant**
  - The organic compounds are dissolved in water to form phloem sap
- Phloem is a complex tissue made up of different cell types; it is mainly made up of **sieve tube elements** and **companion cells**
  - Sieve tube cells, or elements, line up end-to-end to form a **continuous tube** through which phloem sap flows
  - Companion cells are **closely associated with the sieve tube** and aid with the loading and unloading of dissolved substances, or assimilates
- Mature phloem tissue contains **living cells**, unlike xylem cells which are dead at maturity
  - Having a functioning cell surface membrane is important in the sucrose loading and unloading process
- The cells that make up the phloem tissue are highly specialised, meaning that their **structure aids their function**

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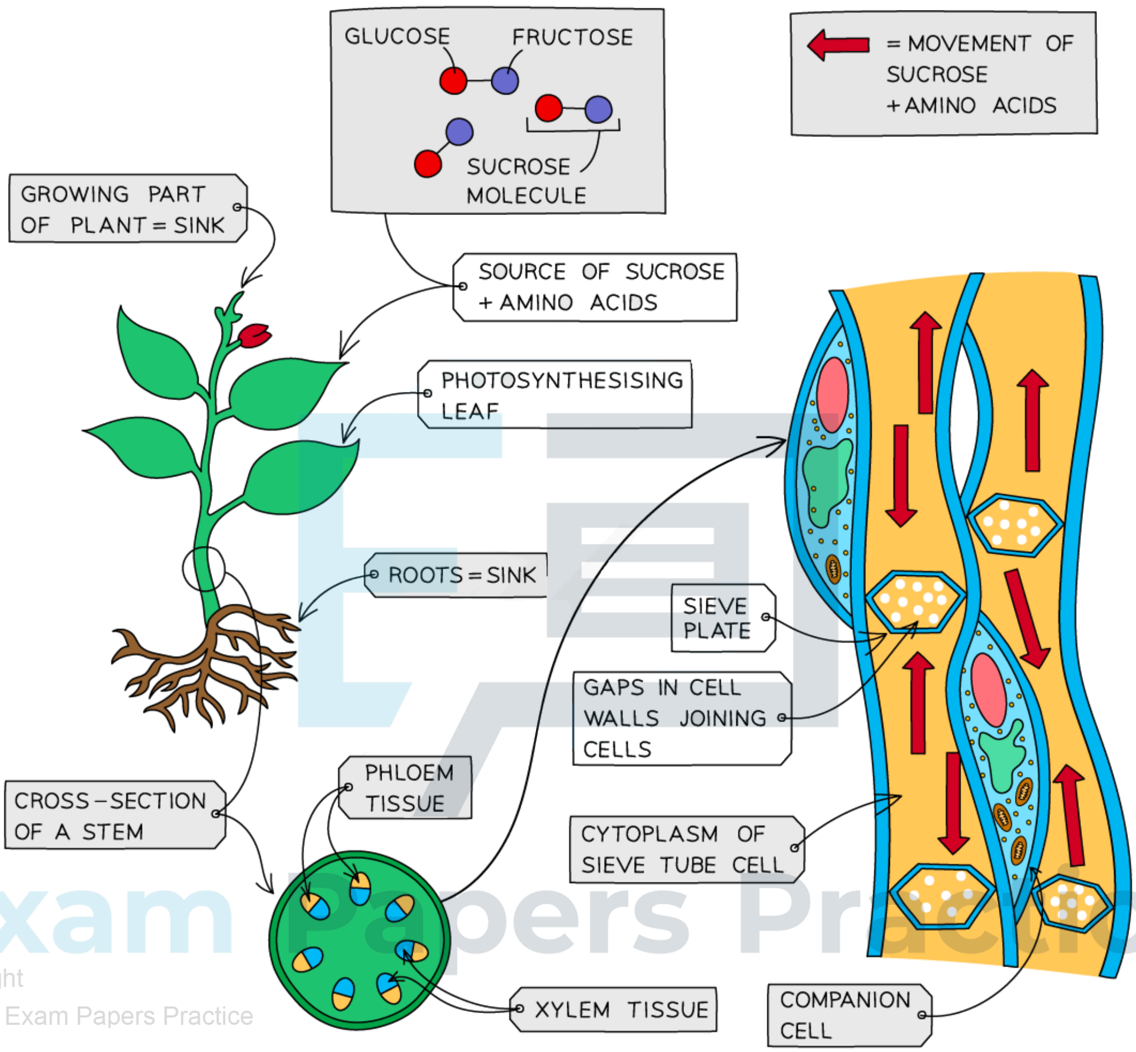

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Phloem tissue contains sieve tube cells and companion cells

Sieve tube structure and function table

Structure	Function
Sieve plates with sieve pores	Allows for the continuous movement of the organic compounds
Cellulose cell wall	Strengthens the wall to withstand the hydrostatic pressures that move the assimilates
No nucleus, vacuole or ribosomes in mature cells (some ER and mitochondria are present)	Maximises the space for the translocation of the assimilates
Thin cytoplasm	Reduces friction to facilitate the movement of the assimilates

Companion Cell Structure and Function Table

Structure	Function
Nucleus and other organelles present, e.g. RER	Provides metabolic support to sieve tube elements and helps with the loading and unloading of the assimilates
Transport proteins in plasma membrane	Moves assimilates into and out the sieve tube elements
Large numbers of mitochondria	To provide ATP for the active transport of assimilates into or out of the companion cells
Plasmodesmata (channels in the cell wall)	The link to sieve tube elements which allows organic compounds to move from the companion cells into the sieve tube elements

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> **Exam Tip**
>
> Understand the difference between sieve tube elements and companion cells, and make sure that you can describe how the **structure** of sieve tube cells is related to their **function**.

9.2.2 Sucrose Loading

Sucrose Loading Mechanism

- Organic compounds such as **sucrose** are transported **from source to sink** through the **phloem sieve tubes**
  - Sucrose is a disaccharide formed from a molecule of glucose and a molecule of fructose
  - Carbohydrates are transported in the form of sucrose because this compound **cannot directly enter the respiration reactions** and so it is less likely to be respired while in the process of being transported
- The pathways that sucrose molecules take when being loaded into phloem sieve tubes at the source include
  - The **apoplast**, or **apoplastic, pathway**
    - Through the **cell wall spaces**
    - This is an **active process** as ion pumps are involved
  - The **symplast**, or **symplastic, pathway**
    - Through the **cytoplasm and plasmodesmata**
      - Plasmodesmata (singular plasmodesma) are **channels through the cell walls** of plant cells that connect neighbouring cells
    - This is a **passive process** as the sucrose molecules move by diffusion

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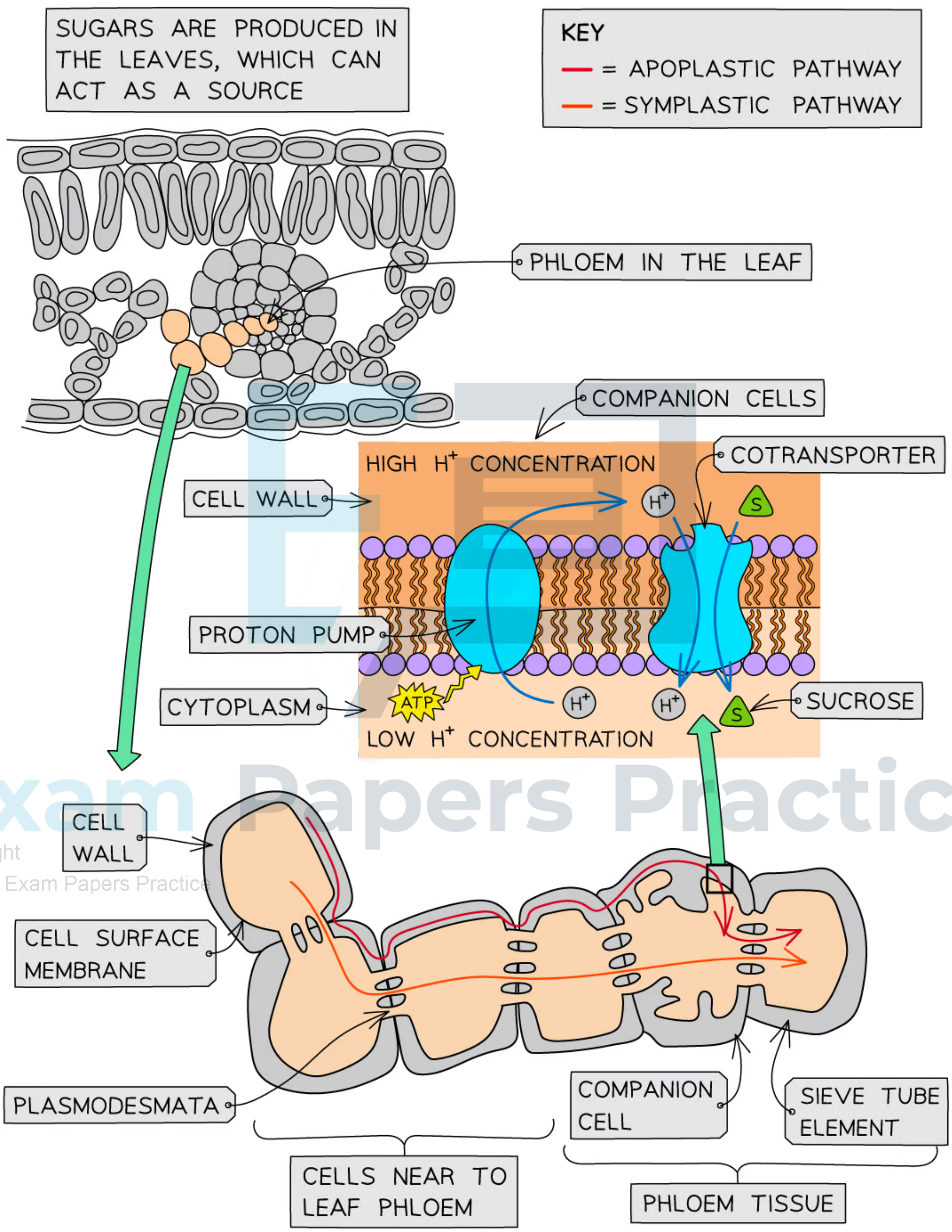
The apoplast pathway

- Sucrose molecules that move along the **apoplast pathway** enter the sieve tube as a result of the following process
  - Companion cells **pump hydrogen ions** out of their cytoplasm into their cell walls
    - This pumping is carried out by proteins known as **proton pumps**
    - This is an **active process** and therefore requires ATP
  - The **high concentration of hydrogen ions in the cell wall space** of the companion cell results in the hydrogen ions **moving down their concentration gradient** back into the cytoplasm
  - The hydrogen ions move via a co-transporter protein, meaning that **whilst transporting the hydrogen ions, this protein also carries sucrose molecules into the companion cell** against the sucrose concentration gradient
  - The sucrose molecules then move into the sieve tubes from the companion cells by **diffusion through plasmodesmata**
- Note that this process takes place inside a specialised type of companion cell known as a **transfer cell;** these cells have a folded cell surface membrane to **increase the available surface area** for the active transport of solutes and **many mitochondria** to provide the energy for the proton pumps
- This mechanism permits plants to **build up the sucrose concentration in the phloem** to many times more than that in the surrounding cells

The symplast pathway

- In some plants sucrose molecules mainly travel **from the cytoplasm of one cell to the cytoplasm of neighbouring cells** by **diffusion through plasmodesmata**



Sugar can enter the sieve tube cells via either the apoplast or symplast pathway. Entry via the apoplast pathway involves proton pump and co-transporter proteins.

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Exam Tip

Remember that the loading of sucrose requires two transport proteins, proton pumps and co-transporter proteins, which are located in the companion cell surface membrane.

9.2.3 Hydrostatic Pressure Gradients

Hydrostatic Pressure Gradients

- Phloem sap containing sucrose and other organic solutes **moves through the sieve tubes down a hydrostatic pressure gradient**
  - This is known as the **pressure-flow hypothesis**
  - Hydrostatic pressure is the term used to describe the **pressure exerted by a fluid on the walls of its container**
- High hydrostatic pressure at the source is generated by the following process
  - Sucrose is **actively transported into the sieve tube elements** at the source
  - The **raised solute concentration** in the sieve tube causes **water to follow the sucrose by** osmosis
  - Water cannot be compressed, so when the volume of water in the sieve tube increases, it **presses against the rigid plant cell walls, resulting in a build-up of hydrostatic pressure** in the sieve tube at the source
- Low hydrostatic pressure at the sink is maintained by the following process
  - **Sucrose is removed from the sieve tube** elements when it reaches the sink
    - Sink regions contain cells where **sugars are either used in respiration or converted into starch** for storage
  - This **lowers the solute concentration of the sieve tube** contents
  - **Water leaves the sieve tube by osmosis**, **lowering the hydrostatic pressure** inside the sieve tube at the sink
- Phloem sap inside the sieve tube moves **down a hydrostatic pressure gradient** from **high to low hydrostatic pressure**
  - The pressure difference between the source and the sink results in the **mass flow of phloem sap** from the high hydrostatic pressure area to the low hydrostatic pressure area
- The direction of the mass flow of phloem sap is determined by the **hydrostatic pressure gradient**, which in turn is determined by the **relative locations of the source and sink regions** in the plant; this means that **phloem sap can flow either upwards or downwards** within the sieve tube

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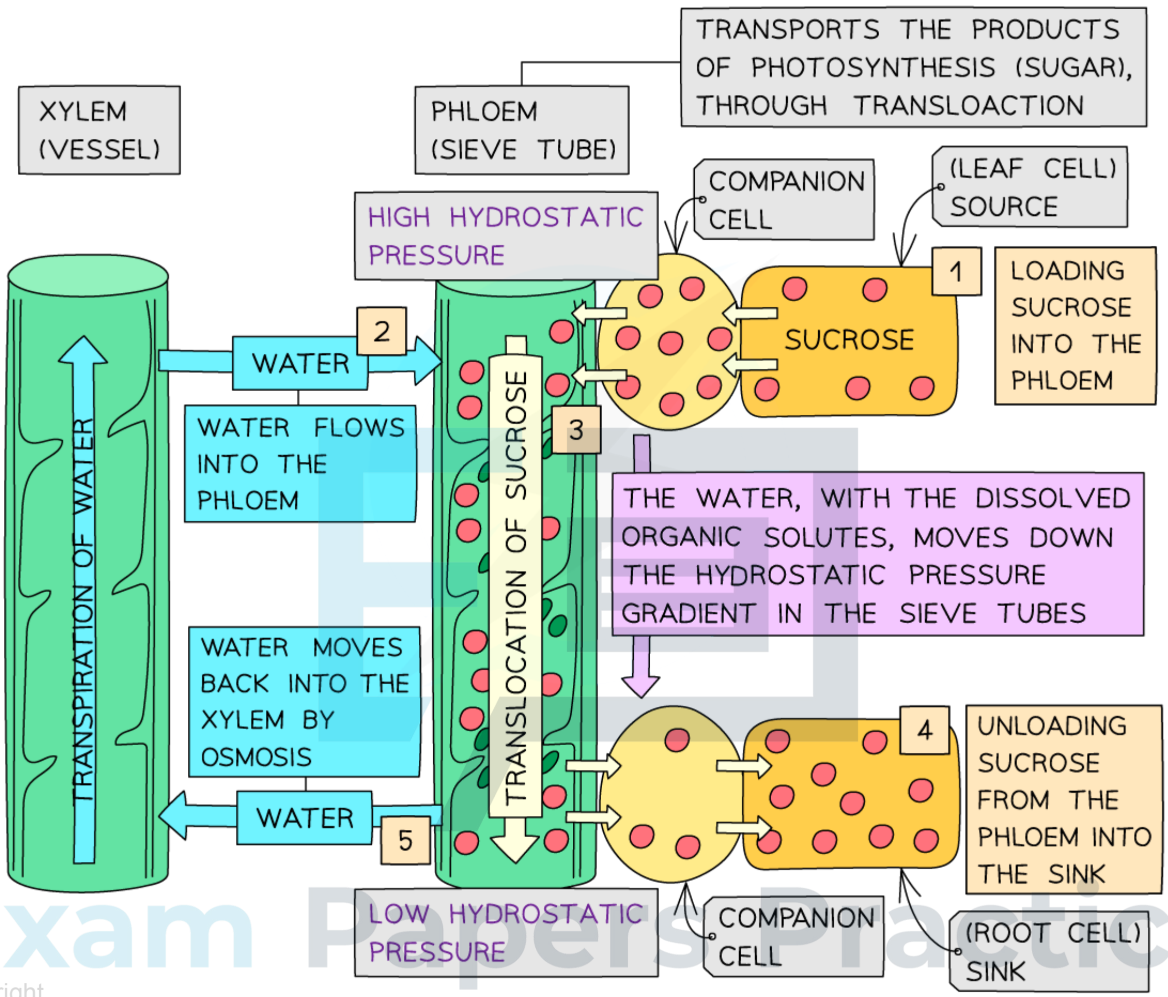

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The translocation of phloem sap occurs due to a hydrostatic pressure gradient between the source and the sink

Exam Tip

Remember that the source will not always be the leaves and the sink will not always be the roots; phloem sap can move both up and down the plant depending on the location of the source and sink regions.

The hydrostatic pressure gradient is dependent on water moving in and out of the xylem vessels by osmosis.

9.2.4 Skills: Identifying Xylem & Phloem

Identifying Xylem & Phloem

Xylem

- The functions of xylem tissue in a plant are:
  - To **transport dissolved minerals and water** up the plant via vascular tissues
  - **Structural support**
- Xylem tissue is found, along with phloem tissue and other tissues, in **vascular bundles**
- The location of the vascular bundles is dependent on which **organ** they are in:
  - In **roots**, the vascular bundle is found in the **centre** and in the **middle of the centre core** is the xylem tissue. This helps the roots withstand the pulling strains they are subjected to as the plant transports water upwards and grows
  - In **stems**, the vascular bundles are located around the **outside** and the xylem tissue is found on the **inside** (closest to the centre of the stem) to help support the plant
  - In **leaves**, the vascular bundles form the **midrib and veins** and therefore usually spread from the centre of the leaf in parallel lines. The xylem tissue is found on the **upper side** of the vascular bundles (closest to the upper epidermis)

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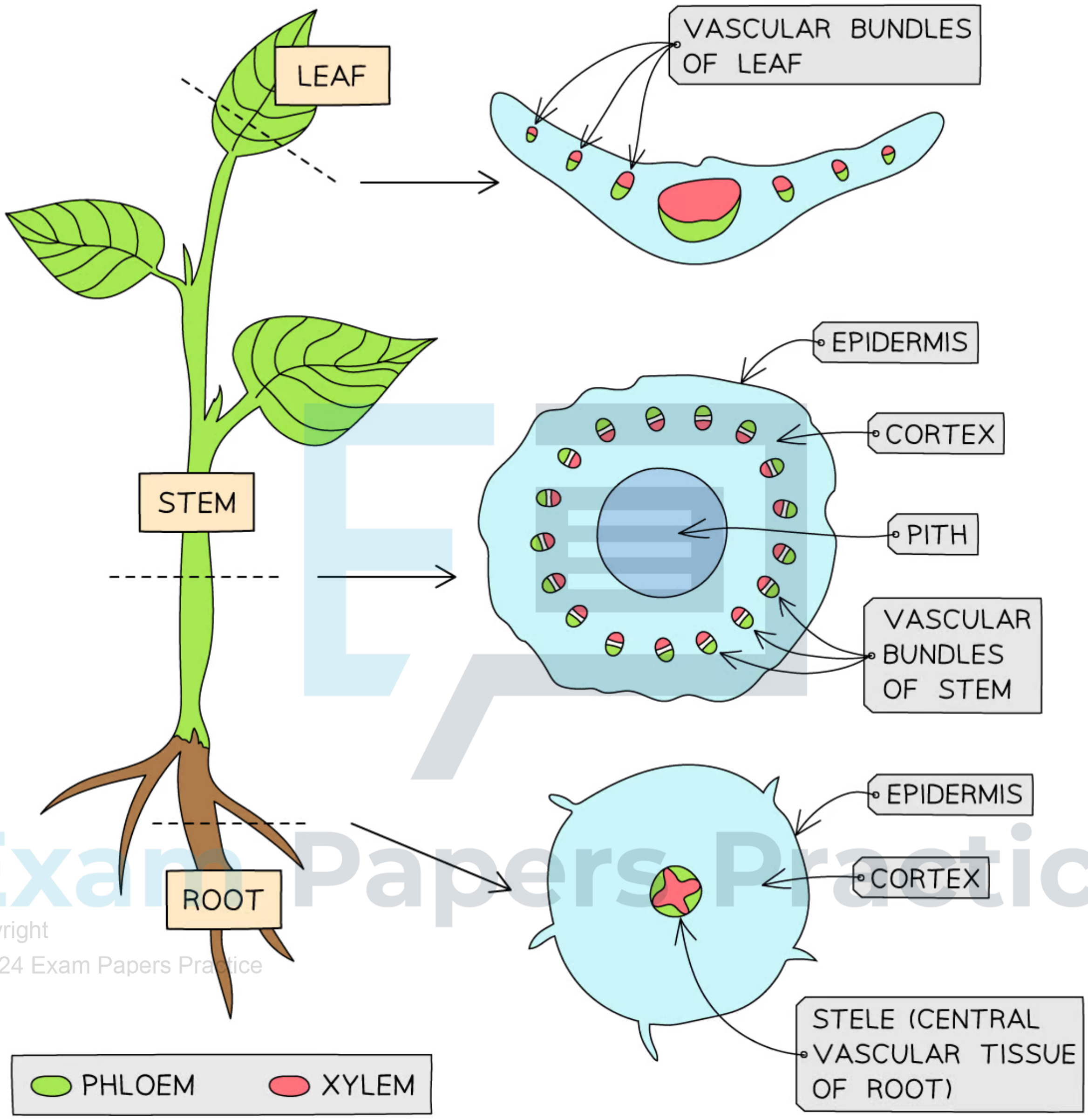

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The distribution of tissue types differs between roots, stems, and leaves.

Phloem

- The function of phloem tissue in a plant is to:
  - **Transport organic compounds**, particularly sucrose, from sources (e.g. leaves) to sinks (e.g. roots). The transport of these compounds can occur **up and down** the plant

- Phloem is a complex tissue also made up of various cell types; its bulk is made up of **sieve tube elements** (which are the main conducting cells) and **companion cells**
- Other cell types within phloem tissue include parenchyma cells (for storage) and strengthening fibres
- The location of the vascular bundles is dependent on which **organ** they are in:
  - In **roots**, the vascular bundle is found in the **centre** and on the **edges of the centre core** is the phloem tissue
  - In **stems**, the vascular bundles are located around the **outside** and the phloem tissue is found on the **outside** (closest to the epidermis on the outer surface of the stem)
  - In **leaves**, the vascular bundles form the **midrib and veins** and therefore usually spread from the centre of the leaf in parallel lines. The phloem tissue is found on the **lower side** of the vascular bundles (closest to the lower epidermis)

Exam Tip

In roots and stem, the xylem tissue is found on the inside – however, in leaves, xylem is found above phloem tissue.

9.2.5 Skills: Measuring Phloem Transport Rates

Measuring Phloem Transport Rates

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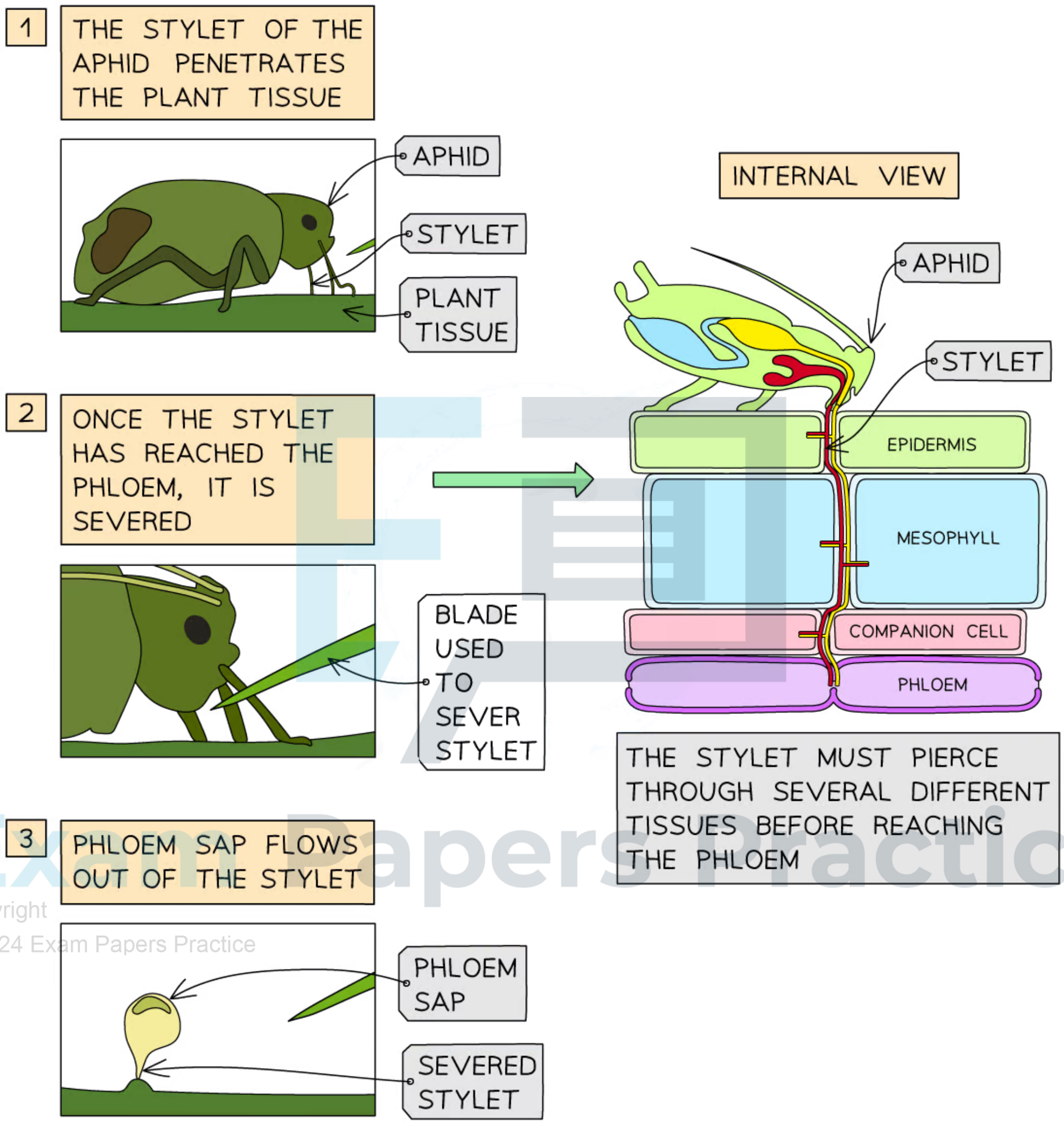
- Hemiptera (also known as true bugs) is an order of insects that have **highly-adapted mouthparts** for **piercing** and **sucking**
- Many hemipterans (such as **aphids**) use these mouthparts for **feeding on phloem sap**
- This behaviour has been used by scientists to investigate **transport in the phloem** of plants to better understand, for example, **how it occurs** and the **speed** at which it occurs

Investigating phloem transport rates using aphid stylets

- Aphids penetrate the phloem using mouthparts known as **stylets** (these are a bit like microscopic pipettes)
- If the aphid is first anaesthetised, its head and body can be removed **leaving the stylet still in place**
- Due to the **pressure** of phloem sap in the sieve tube, sap will **continue to flow** out of the stylet, forming a drop at the end of the severed stylet
- At this point, the **flow rate** of the phloem sap can be measured and a **sample** can be taken from it to analyse its **composition**



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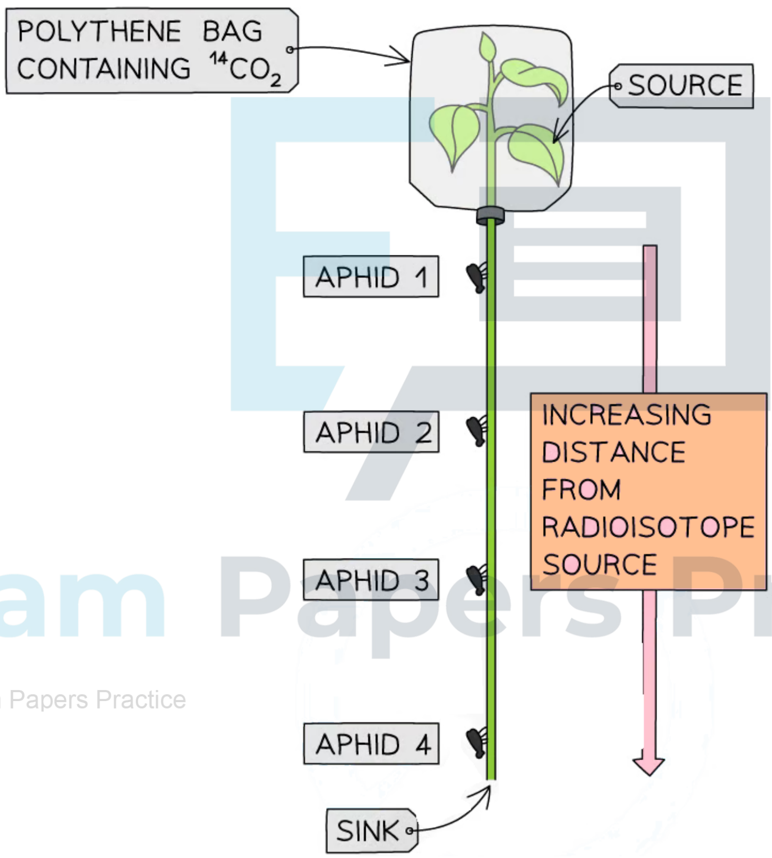
Aphids can be used by scientists to investigate transport in the phloem of plants

NOS: Developments in scientific research follow improvements in apparatus; experimental methods for measuring phloem transport rates using aphid stylets and radioactively-labelled carbon dioxide were only possible when radioisotopes became available

- Using **radioactive isotopes** (also known as radioisotopes) in scientific research only became possible after 1945 because their use was developed for work on the atomic bomb during the Second World War
- For example, **carbon-14** (^{14}C) is an **isotope** of carbon that is **radioactive**
  - It is possible to generate **carbon dioxide that contains carbon-14**; this would be written as $^{14}CO_2$
- It was discovered that if leaves were exposed to **$^{14}CO_2$** whilst they were **photosynthesising** (by surrounding a leaf with a polythene bag filled with $^{14}CO_2$), the **leaves would produce ^{14}C-labelled sugars**
- Using autoradiography, these ^{14}C-labelled sugars could then be **traced during translocation throughout the plant** and also **detected in phloem sap flowing out** of aphid stylets
- These techniques enabled scientists to investigate the **speed of phloem transport** and how sugars are **distributed between sources and sinks** in plants



EXAMPLE RESULTS TABLE

Aphid number	Distance from radioisotope (^{14}C) source (cm)	Time for radioisotope (^{14}C) to reach aphid (hours)	Rate of phloem transport (cm hr^{-1})
1	10	0.75	13.3
2	20	1.40	14.3
3	30	2.32	12.9
4	40	2.75	14.5

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^{14}C-labelled sugars can be traced during translocation throughout planta by detection in phloem sap flowing out of aphid stylets

- Sugars are **produced** in sources (photosynthesising leaves) while sugars are **delivered to** sinks (roots, young shoots and developing seeds)

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