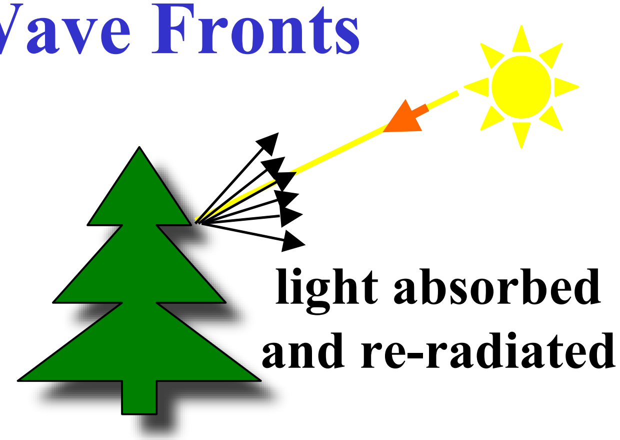
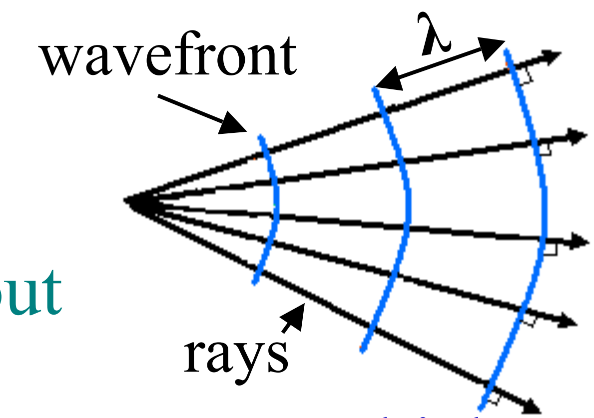
Recap: Light "Rays" and Wave Fronts



- **Light** from a source is **scattered** in **all directions** from **any** given **point**.
- Each and **every part** of an **object** therefore acts as (secondary) **source** of **light waves** that **radiate uniformly** from that point.
- These waves spread out (diverge) as they propagate away from the object and can be easily represented by **"light rays"**.
- Light **rays** are **always perpendicular** to the **wavefronts**.

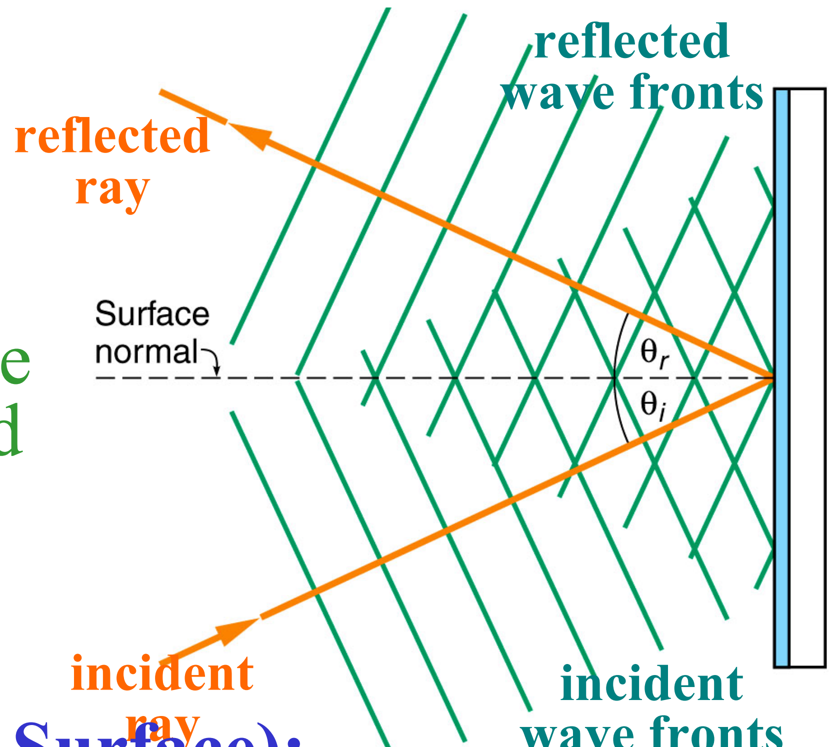


- Each wavefront is **separated** by **one wavelength**.
- Wavefronts (from all points) **combine together** and **carry** the **information** about the **shape** of the object.
- Wavefronts are complex and it is easier to use rays which are straight lines (for any given medium, e.g. glass, air).

Reflection

Plane waves reflecting in a mirror at an angle:

- The **light rays** (wavefronts) strike mirror at an **incident angle θ_i** and are **reflected** off the mirror at **<u>same speed</u> at angle θ_r** .



Law of Reflection (Smooth Surface):

❖ The **angle** the **reflected ray** makes with the **normal** to the surface of reflection **equals** the **angle of incidence**:

$$\theta_i = \theta_r$$

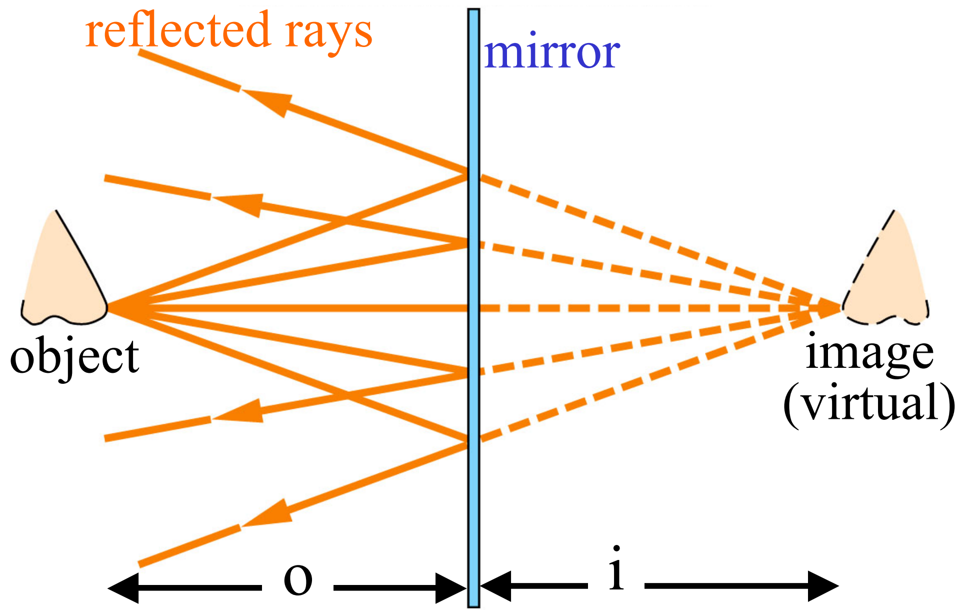
(Note: This is because the light waves **travel** at **<u>same speed</u>** **before** and **after reflection**.)

- The **reflected ray** always lies in **same plane** as **incident ray** and the **surface normal**.

Images in Plane Mirrors

- By **extending** the **reflected rays backwards** from the mirror, they all **intersect** at **a point behind** the mirror.

- Your eye sees the **reflected rays** and you perceive a "**virtual**" image that appears to lie at this **point of intersection**. (light appears to come from this point.)

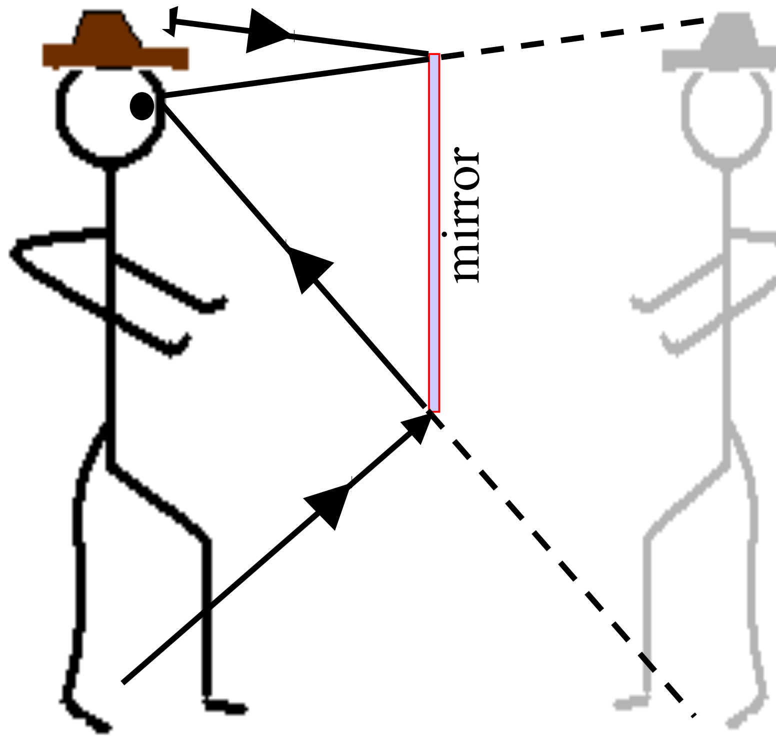


- This situation holds for **every point** on the object…and your face seems to **lie behind the mirror (a <u>virtual</u> image)**.
- By geometry, the distance of image behind mirror '**i**' equals the distance of object in front of the mirror '**o**'.

$$\mathbf{i = o}$$

Question: How big does a mirror need to be in order to see your whole body?

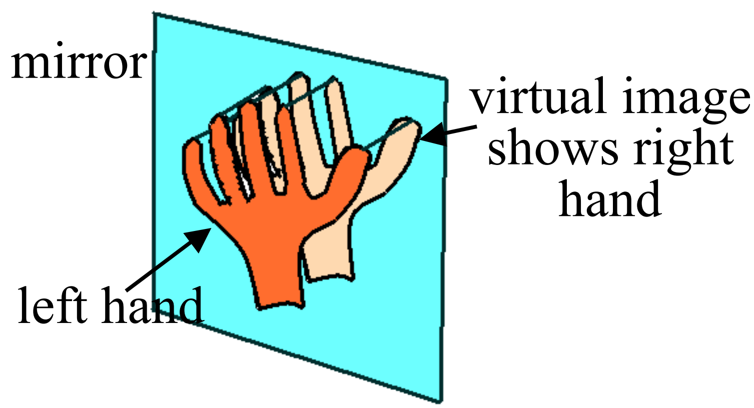
- **Answer**: Mirror needs to be half your height with its upper edge lowered by half distance between your eye and top of your hat!



- Images formed in a plane mirror are **virtual** images (as the light does not pass through the image).
- Images are **upright** (right side up) and **same size** as object (no magnification) but are **laterally** (left ↔ right) **inverted**.

<u>**Lateral Inversion**</u>:

- **Left hand** becomes a life-size image of a **right hand**!



Refraction

- What happens to **light waves** when they enter a **transparent material** such as glass, H_20, plastic etc?
- Individual "**photons**" **collide** with **atoms** and are **absorbed** and **immediately re-emitted** (i.e scattered).
- Typically there are **billions** upon **billions** of **photons absorbed**, **re-emitted**, and **absorbed again** and **again** as light beam makes its way through the medium.
- The **net effect** of this process is that the **light waves effectively propagate** at a **speed lower than 'c'** (even though individual photons **do not exist** at any speed other than 'c'!).
- The **difference in speed of light** in **different materials** is called the **index of refraction 'n':**

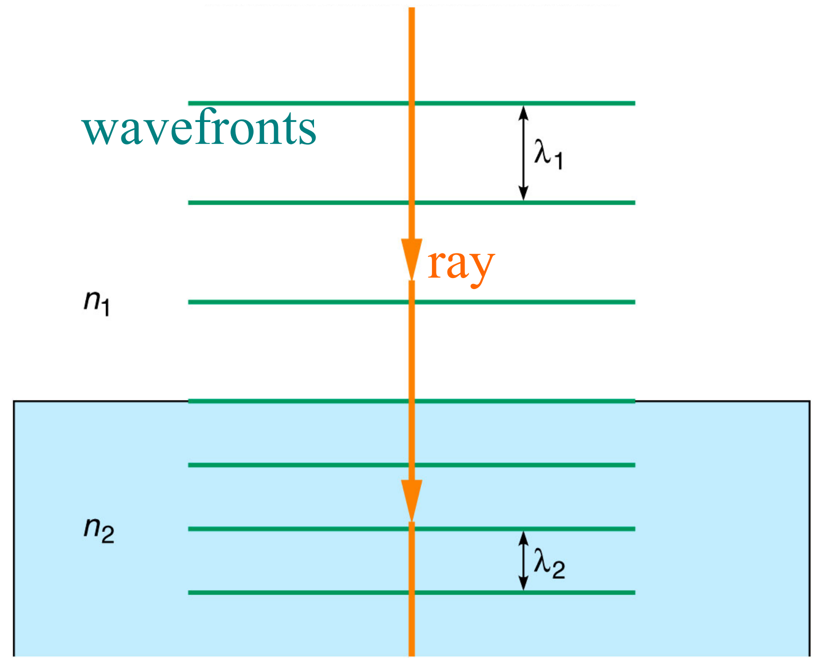
$$\mathbf{n = \frac{c}{v}}$$

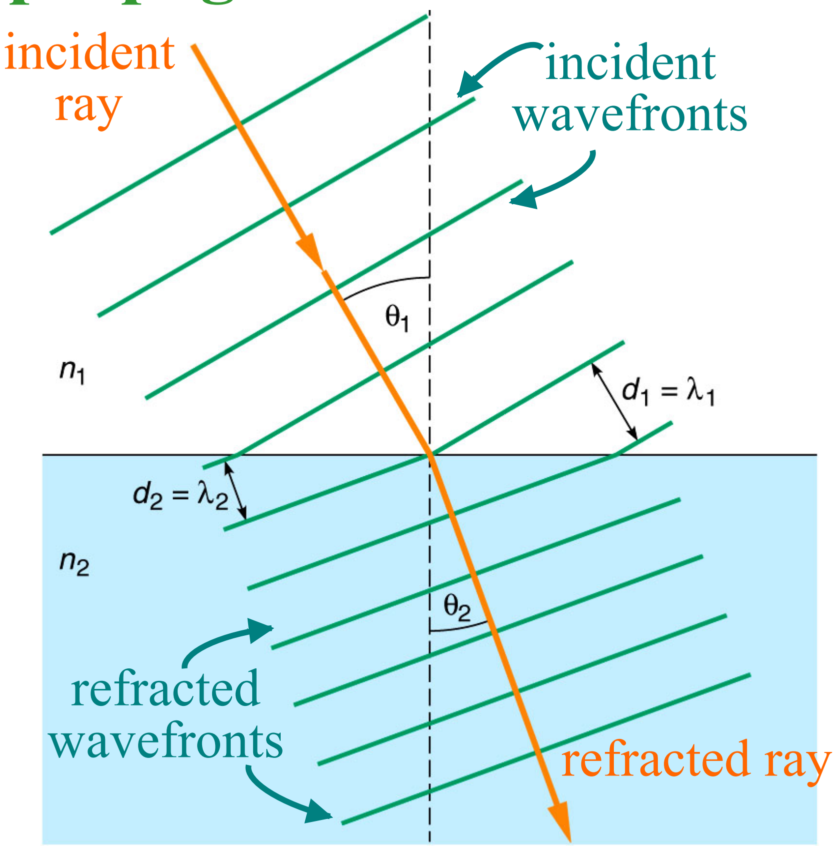
c = speed of light
v = speed in medium

- **Typical values** of n = 1.5 or 1.6 (glass) which means light speed is ~ two thirds of speed in air /vacuum.

Normal Incidence:

- The reduced speed results in a **decrease** in wavelength of the light in the higher 'n' medium.
- Effect of **reduced speed** and **wavelength** on **light ray propagation** in medium:





Result:

- **Wave fronts** are **bent** (**refracted**) at the **surface** due to **difference** in **propagation speed**.
- Refracted ray **no longer parallel** to incident ray (except at normal incidence)

- **Amount** of **bending** depends on:
  - **angle** of incidence
  - **refractive index** of medium
- A **large difference** in **refractive index** produces a **large bend** in the **light ray**.

Snell's Law:

❖ **When light passes from one transparent medium to another, the rays will be bent <u>towards</u> the normal if the refractive index of medium is larger.**

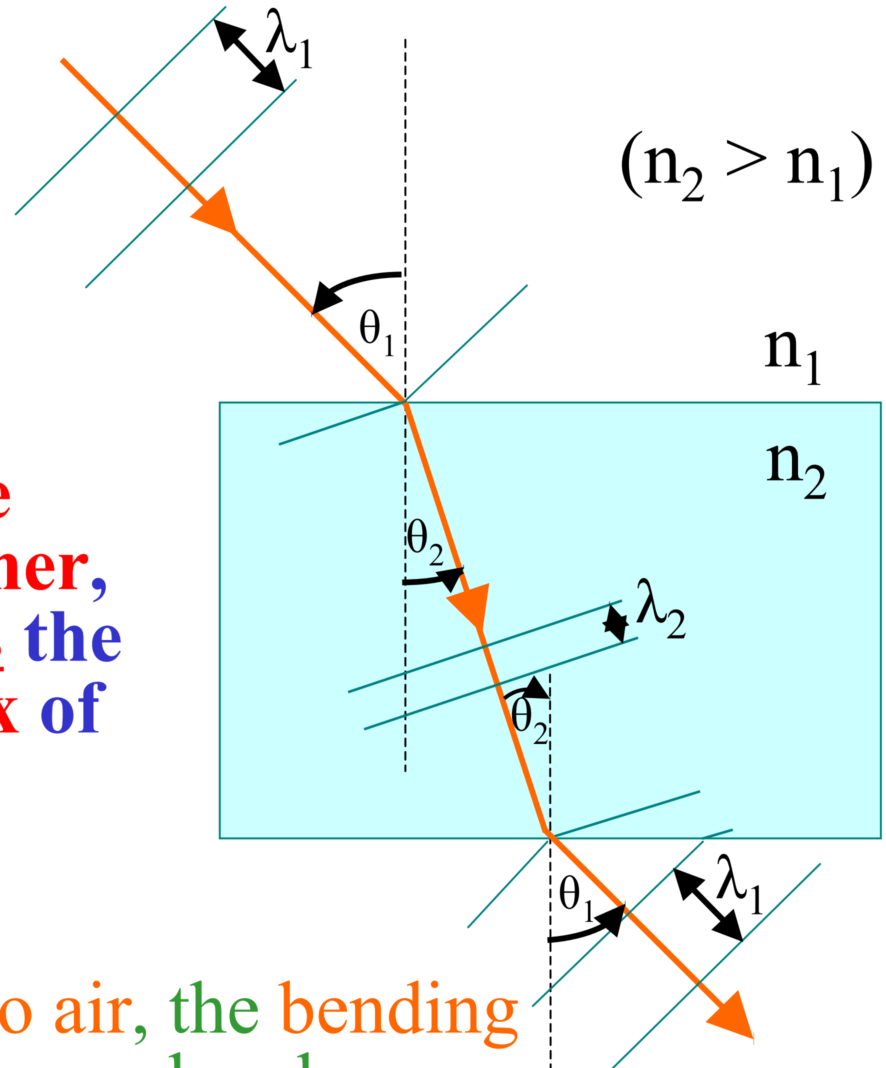
$$n_1 . \sin\theta_1 = n_2 . \sin\theta_2 \quad \text{or} \quad \frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$

Note: For **small angles:** $\sin\theta \rightarrow \theta$ (in radians).

- When light travels from glass to air, the bending is in the **opposite direction** (i.e. rays bend **away** from normal when going from high to low 'n' medium).
- **Remember: Light rays** are **reversible!**

Summary: Refraction

- **Amount** of **bending** depends on:
  - **angle** of incidence
  - **refractive index** of medium



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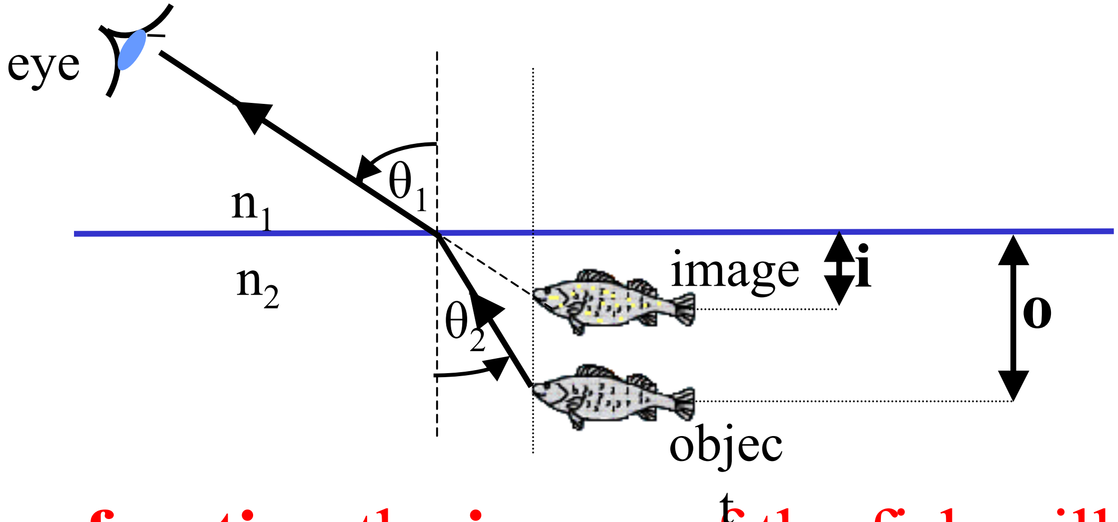
- **Example of refraction**: Viewing objects **under water**…



- Due to **refraction** the **image** of the fish will **appear closer** to the surface than it actually is.
- **Relationship for apparent depth:**

$$\mathbf{i = o\left(\frac{n_1}{n_2}\right)} \qquad \text{(provided } n_2 > n_1\text{)}$$

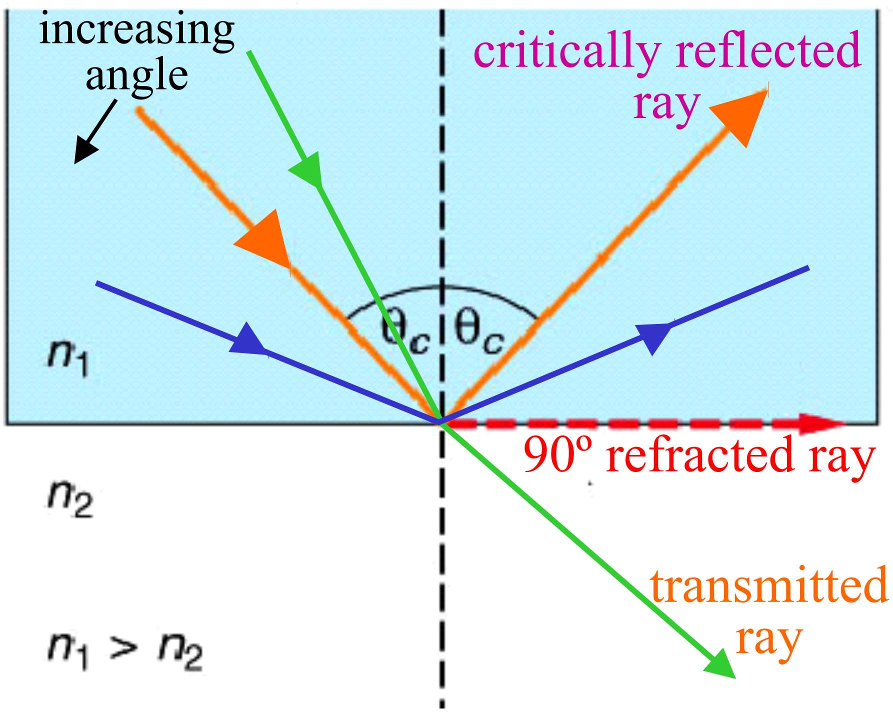
- E.g. If n_2 (water) = 1.33 what is the apparent depth of a fish at 2 m depth?

$$i = 2 \times \left(\frac{1}{1.33}\right) = 1.5\ \text{m}$$

- The fish is 0.5 m below its image (virtual image) and is safe!

Total Internal Reflection

- When **light travels** from a **high** to a **lower refractive index** medium (as with the fish looking at us) the **ray** is **bent away** from normal.
- Depending on 'n', a critical angle of incidence (θ_c) can be reached where the **angle of refraction = 90º.**



- When the angle of **refraction equals 90º,** the ray is **no longer transmitted** but is instead **totally internally reflected** at the interface.
- At angles **equal** or **greater** than **critical value** (~42º for glass, n=1.5) **100%** of **light** is **reflected** creating a **perfect mirror**!

Note: On **transmission** some light is always lost to **reflection** within the medium.