The pinna directs sound waves into the ear.

The oval window and the round window separate the fluid-filled inner ear from the air-filled middle ear.
1. Sound waves strike the tympanic membrane and become vibrations.
2. The sound wave energy is transferred to the three bones of the middle ear, which vibrate.
3. The stapes is attached to the membrane of the oval window. Vibrations of the oval window create fluid waves within the cochlea.
4. The fluid waves push on the flexible membranes of the cochlear duct. Hair cells bend and ion channels open, creating an electrical signal that alters neurotransmitter release.
5. Neurotransmitter release onto sensory neurons creates action potentials that travel through the cochlear nerve to the brain.
6. Energy from the waves transfers across the cochlear duct into the tympanic duct and is dissipated back into the middle ear at the round window.

Diagram:
- Ear canal
- Malleus
- Incus
- Oval window
- Stapes
- Movement of sound waves
- Cochlear nerve
- Vestibular duct (perilymph)
- Cochlear duct (endolymph)
- Tympanic duct (perilymph)
- Tympanic membrane
- Round window
**SENSORY CODING FOR PITCH**

(a) The basilar membrane has variable sensitivity to sound wave frequency along its length.

High frequency (high pitch)

Low frequency (low pitch)

Stiff region near round window

Flexible region near helicotrema (distal end)

(b) The frequency of sound waves determines the displacement of the basilar membrane. The location of active hair cells creates a code that the brain translates as information about the pitch of sound.

Eardrum

Oval window

Basilar membrane

Helicotrema

Basilar membrane unwound (top view)

Basal end

Apical end

Relative motion of basilar membrane (μm) vs. Distance from oval window (mm) for:

- **100 Hz**
  - Distance from oval window (mm)

- **400 Hz**
  - Distance from oval window (mm)

- **1600 Hz**
  - Distance from oval window (mm)
(a) Induction coils record movement of bird's head.

(b) Speaker on track; track can be raised and lowered.

Horizontal: 0° = Straight ahead, 90°
Elevation: Constant distance
Azimuth:
Figure 21-17 Bat echolocation sounds and modifications of the nose to broadcast them. The sound spectrogram analysis is of the frequency-modulated (FM) pulses emitted by the little brown bat, Myotis lucifugus, during an interception maneuver. Frequency in kilohertz is plotted against time during the continuous 1-second record. Filled stars indicate typical loud pulses near the time of detection of the target; open stars indicate the onset and completion of the terminal buzz just before capture of prey. (After M. S. Gordon et al., 1982, Animal Physiology, Principles and Adaptations, 4th edition, Macmillan, New York, NY.)

Typical call pattern of a mustached bat

- The CF portion of the bat's cry is many milliseconds long.
- The cry ends in a short FM downswEEP.
Figure 21–18 Proposed odontocete echolocation sound production and reception apparatus shown for the bottle-nosed dolphin (Tursiops). Sound produced by air shuttled between air sacs through the nasal valve is focused by the oil of the melon into a forwardly directed beam. Some sound may also be guided by the mesorostral cartilage. Returned sound is channeled through the mandibular (jaw) fat bodies and especially the acoustic window on the lower jaw to the otherwise isolated and fused middle and inner ears. (Modified after K. S. Norris, 1966, in Evolution and Environment, edited by E. T. Drake, Peabody Museum Centenary Volume, Yale University, New Haven, CT.)
(a) On a horizontal surface

The straight-run, waggle component of the dance points to the food source.

(b) Inside the hive on a vertical surface

The sun's position is encoded as straight up.

The angle $\theta$ between vertical and the waggle run codes the angle between the sun and the food source.
Both the direction and the inclination angle of the magnetic field can give compass information.
(a) Diagram of a snake's facial pit, showing:
- Outer chamber of facial pit
- Inner chamber of facial pit
- Branch of trigeminal nerve (Vth cranial nerve)
- Membrane

(b) Diagram showing:
- Object in front stimulates both pits
- Object on left stimulates left pit
- Object on right stimulates right pit
(b) Light cell in dark state

In the dark state, the mitochondria intercept O$_2$, and the light-emitting reactions cannot go to completion.

(c) Light cell in flashing state

In the flashing state, nitric oxide is produced under nervous control and bathes the mitochondria, preventing them from intercepting O$_2$.

Pulses of O$_2$ reach the luciferin reactions, resulting in pulses of light.
### TABLE 9-5
Types of electric fish, their distribution, and the nature of their electric discharge. *(Modified from Bennett 1971.)*

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Family</th>
<th>Distribution</th>
<th>Electric Organ Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skates</td>
<td>Rajidae</td>
<td>Marine</td>
<td>Weak pulse</td>
</tr>
<tr>
<td>Mormyrids</td>
<td>Mormyridae</td>
<td>Freshwater</td>
<td>Weak pulse</td>
</tr>
<tr>
<td>Gymnarchus</td>
<td>Gymnarchidae</td>
<td>Freshwater</td>
<td>Weak wave</td>
</tr>
<tr>
<td>Gymnotid eels</td>
<td>Gymnotidae, Sternopygidae, Rhamphichthiidae, Apterontidae¹</td>
<td>Freshwater</td>
<td>Weak pulse and wave</td>
</tr>
<tr>
<td>Stargazers</td>
<td>Uranoscopidae</td>
<td>Marine</td>
<td>Strong (5 V) pulse</td>
</tr>
<tr>
<td>Electric rays</td>
<td>Torpedinidae</td>
<td>Marine</td>
<td>Strong (60 V) pulse</td>
</tr>
<tr>
<td>Electric catfish</td>
<td>Malapteruridae</td>
<td>Freshwater</td>
<td>Strong (300 V) pulse</td>
</tr>
<tr>
<td>Electric eel</td>
<td>Electrophoridae</td>
<td>Freshwater</td>
<td>Strong (&gt;500 V) pulse</td>
</tr>
</tbody>
</table>

¹ Neurogenic electric organ.

---

#### Diagrams

**a)** Pacemaker nucleus

**b)** Pacemaker nucleus

**c)** Pacemaker

**High EOD frequency**

**Low EOD frequency**