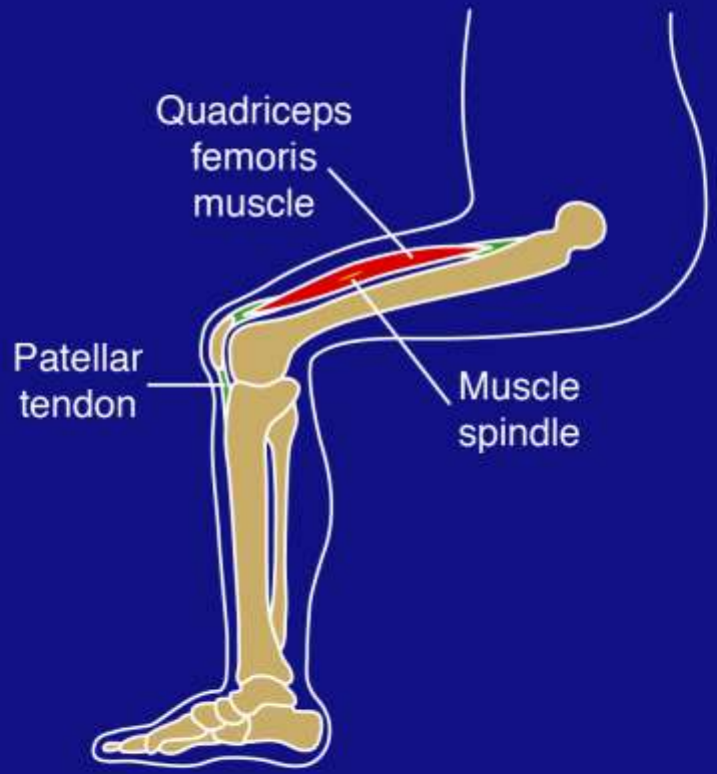
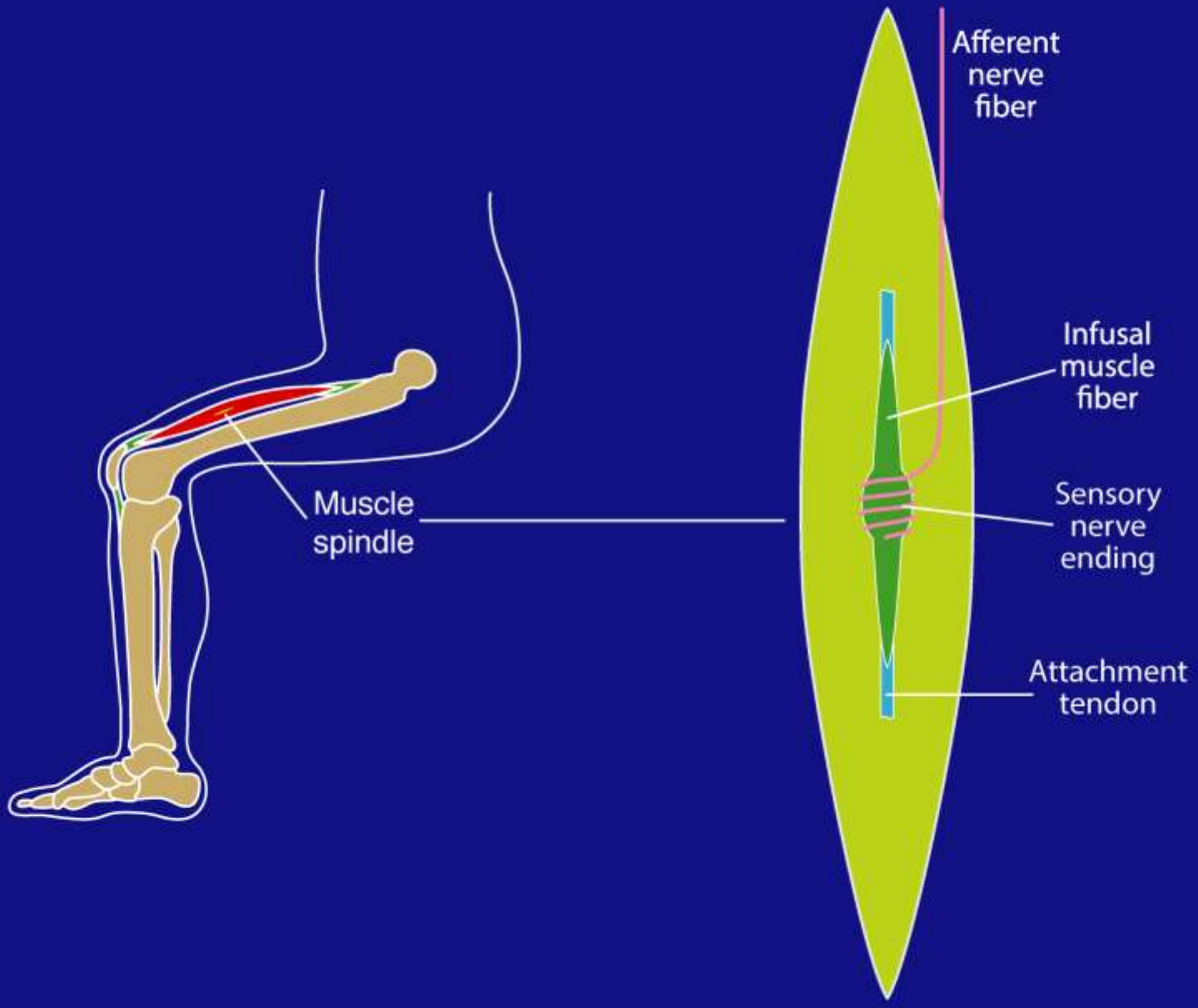
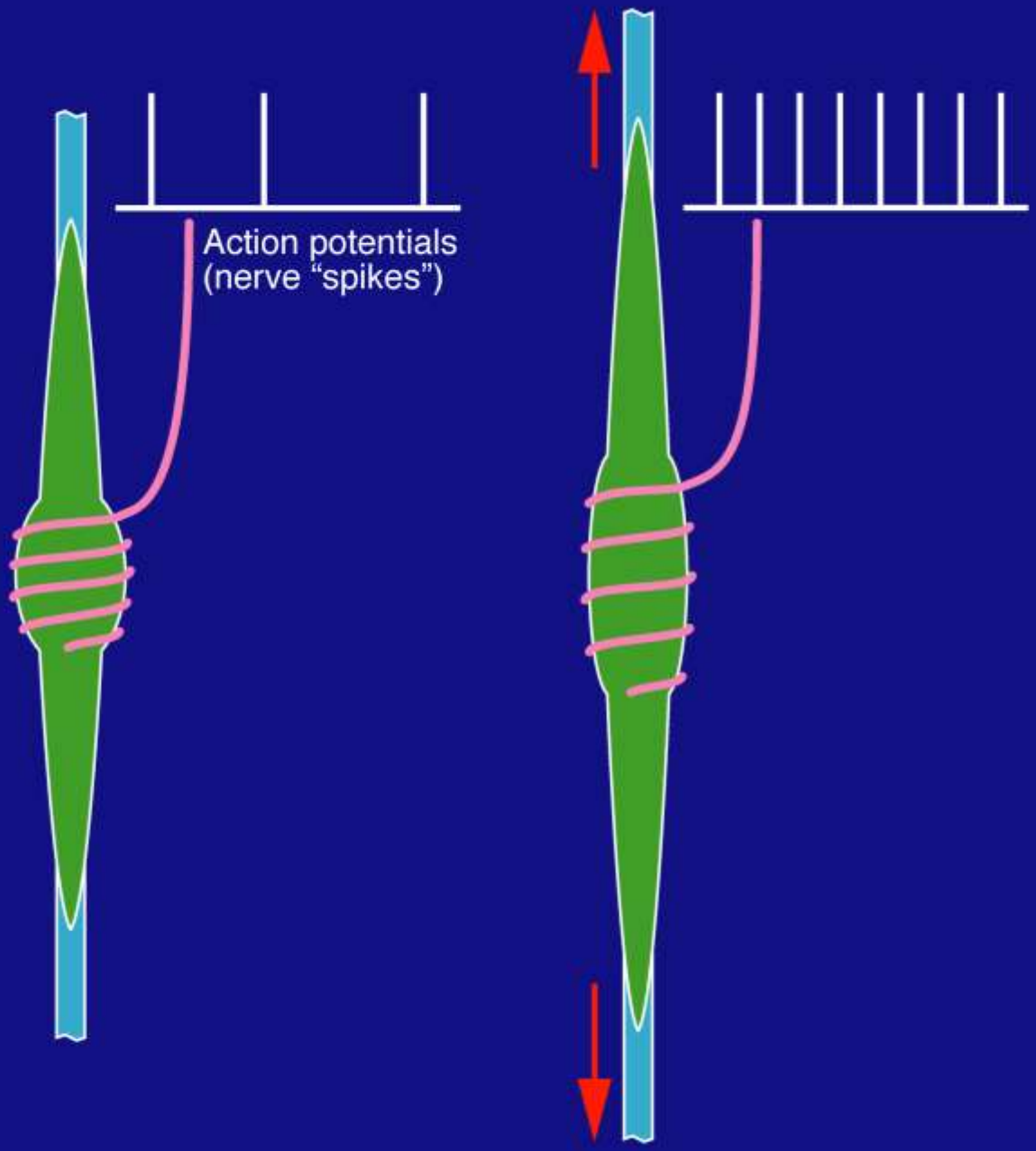
THE VARIETY OF SENSES

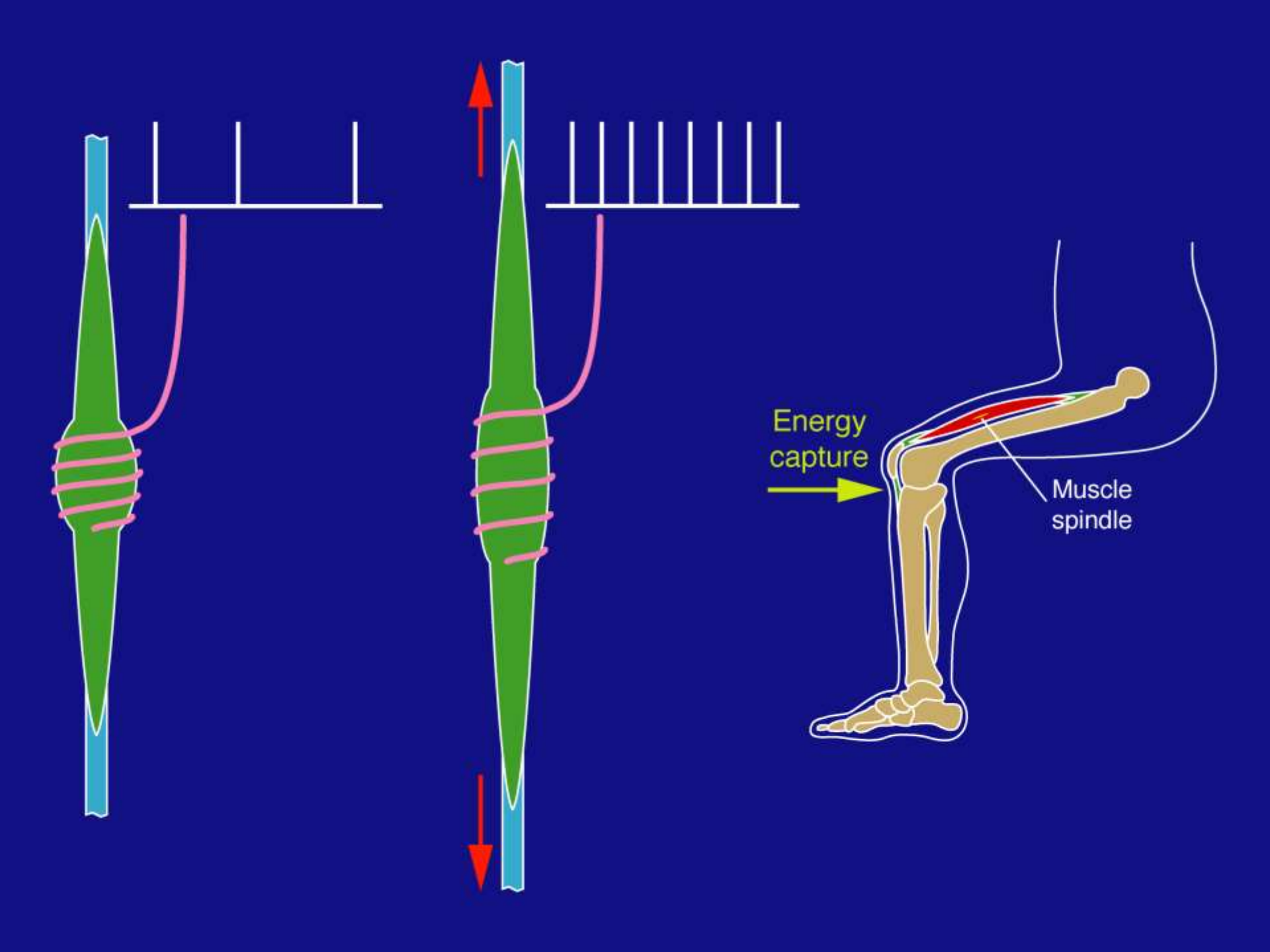
Conventional human senses	
Vision	eyes
Hearing	cochleas of internal ear
Touch	skin
Smell	nose
Taste	tongue, palate
Other human senses	
Blood pressure	aortic body
Blood CO_2 concentration	carotid bodies, aortic body
Blood O_2 concentration	carotid bodies, aortic body
Blood pH (acidity)	carotid bodies, aortic body
Linear acceleration	utricule and saccule of vestibular labyrinth
Angular acceleration	semicircular canals of vestibular labyrinth
Itch	skin
Pain	skin, viscera
Heat	skin
Cold	skin
Muscle tension	skeletal muscles
Joint position	skeletal joints
Additional non-human senses	
Infrasound	birds, elephants
Ultrasound	bats, whales
Magnetoreception	birds
Remote thermoreception	snakes

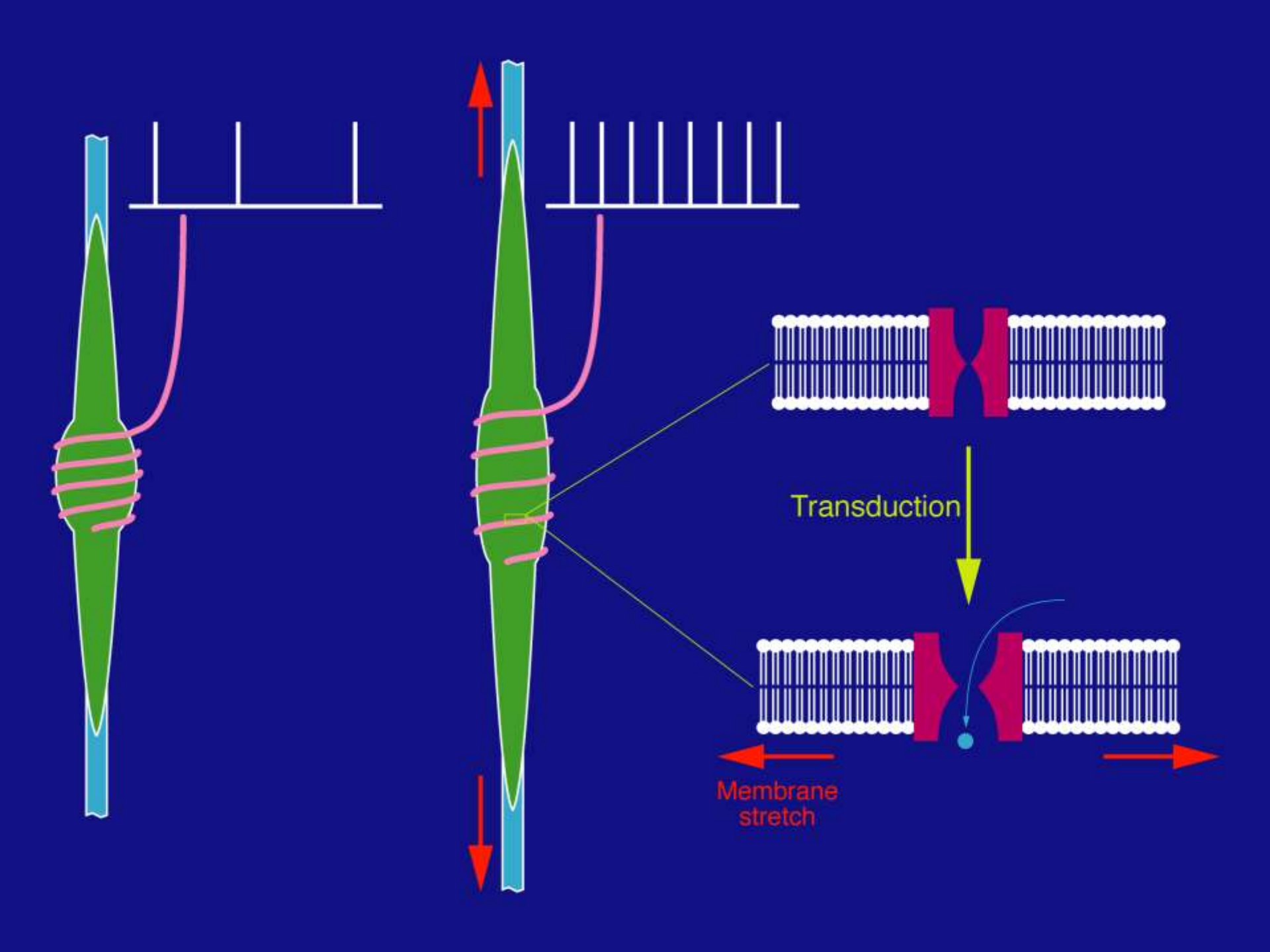
THE KNEE – JERK REFLEX

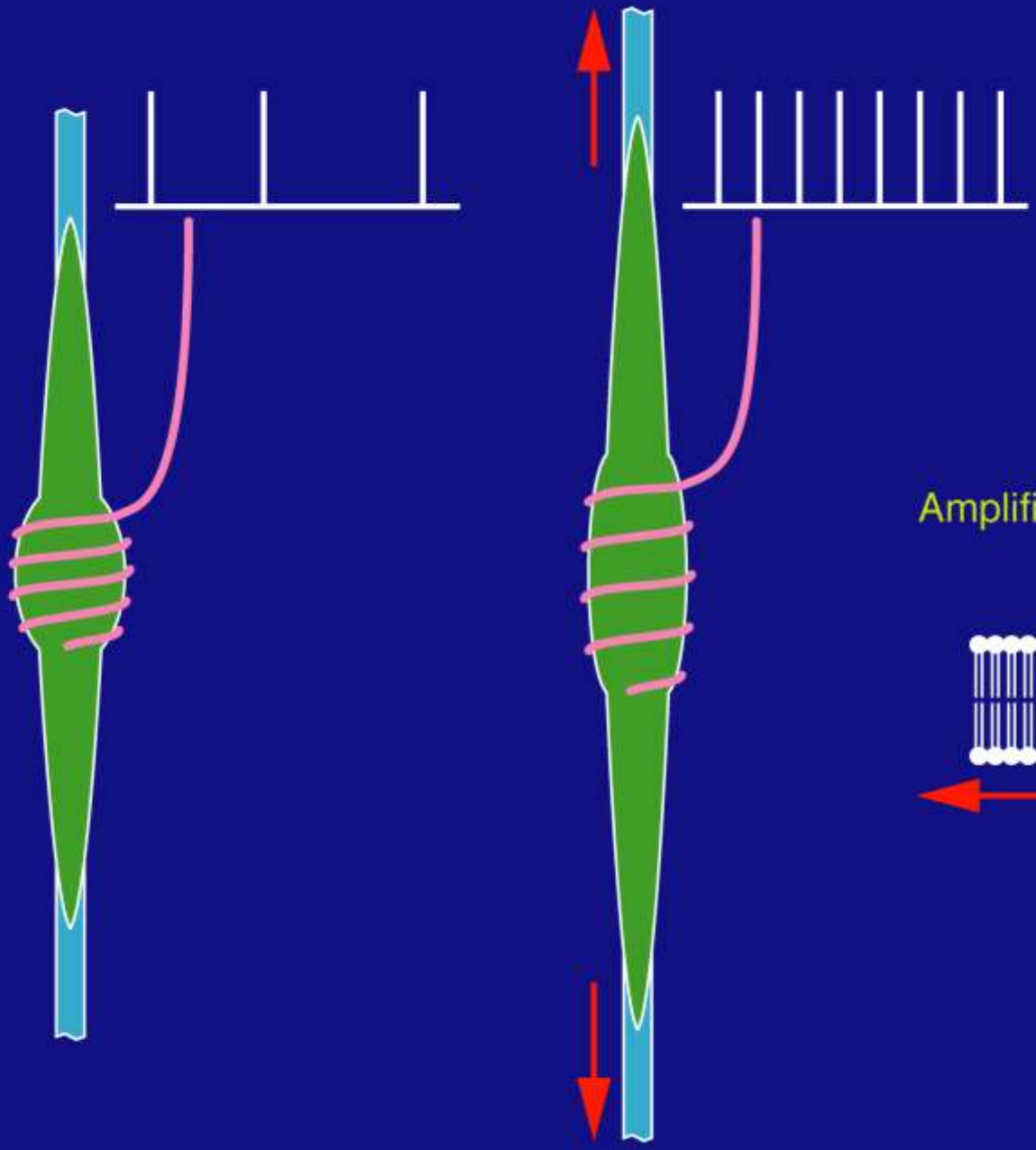



Afferent
nerve
fiber
Infusal
muscle
fiber
Sensory
nerve
ending
Attachment
tendon
Muscle
spindle

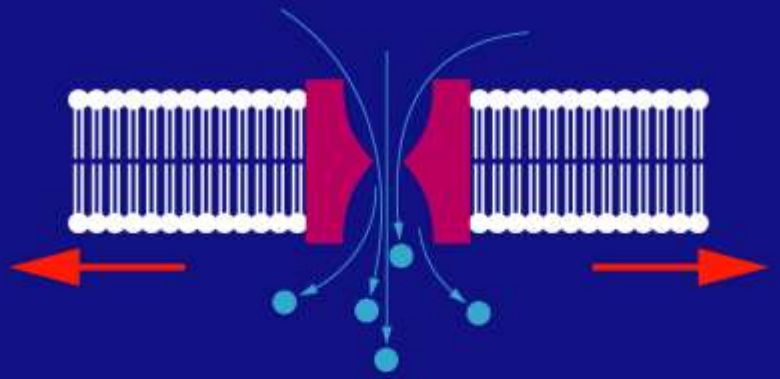

Action potentials
(nerve “spikes”)

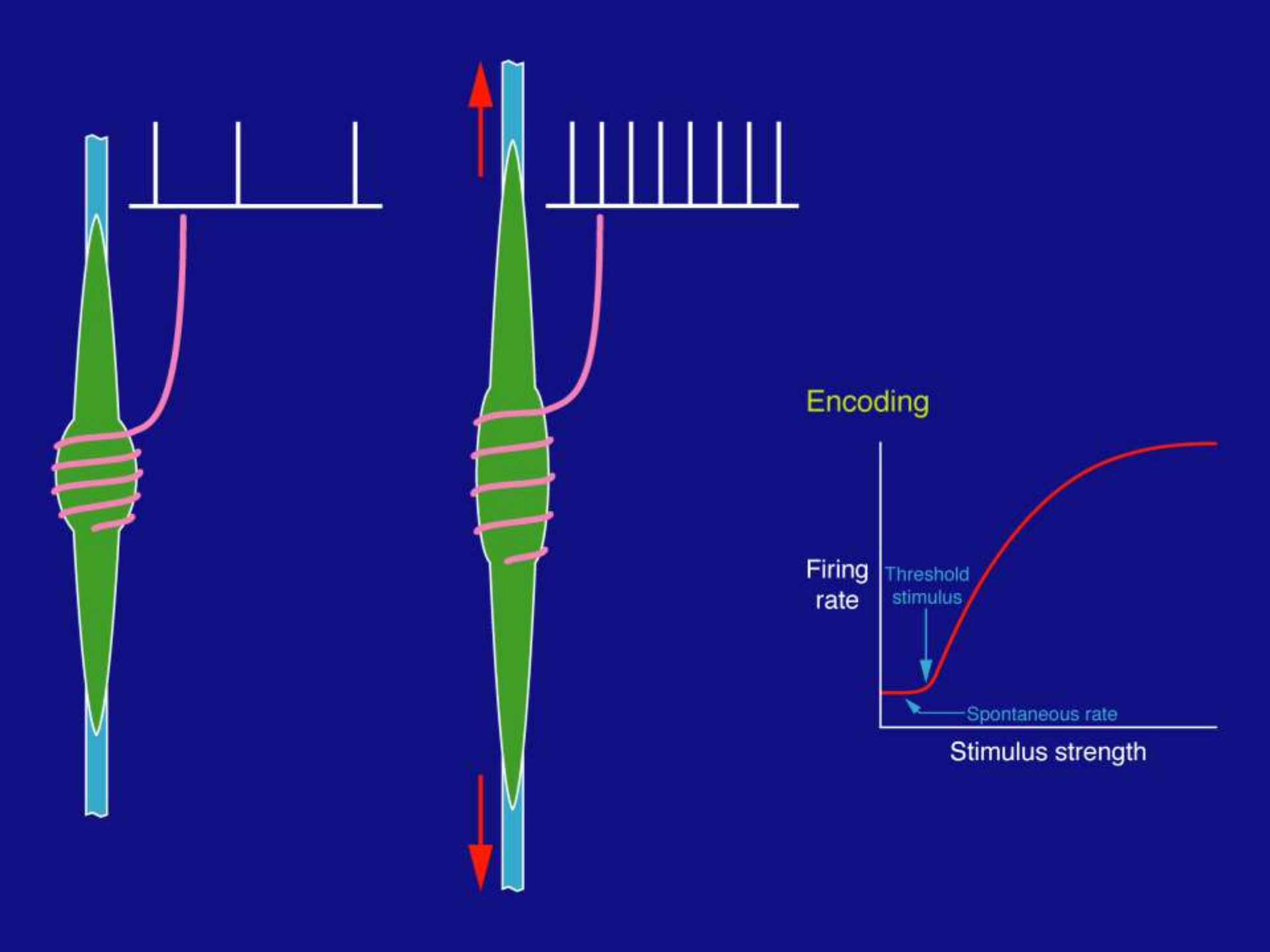

Energy
capture
Muscle
spindle


Transduction
Membrane
stretch

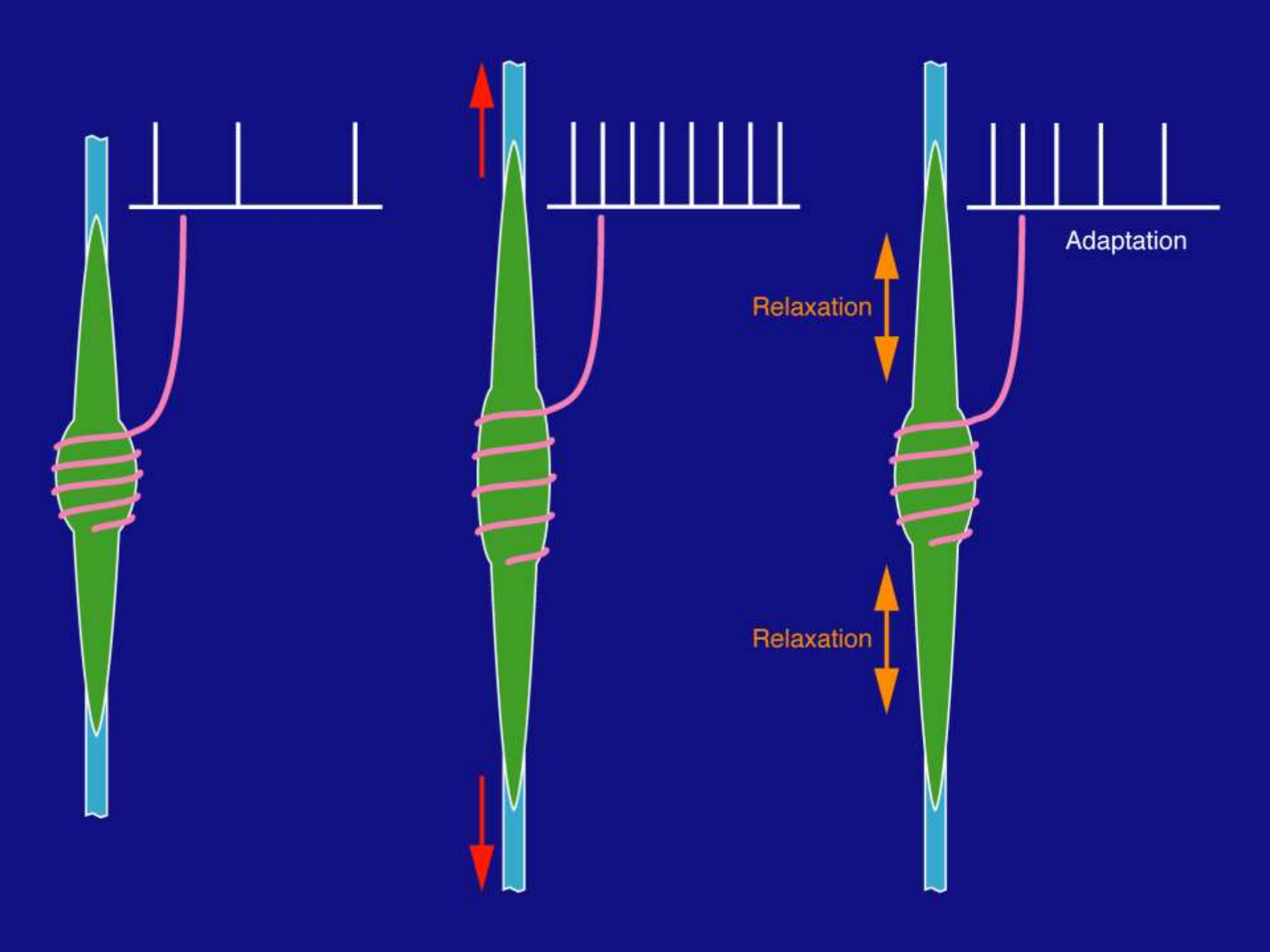


Amplification

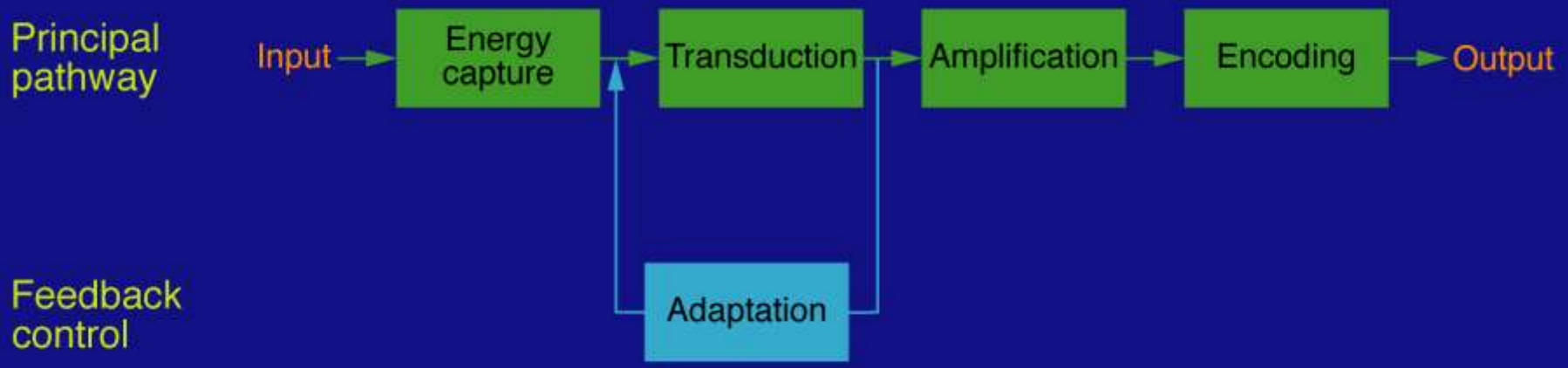


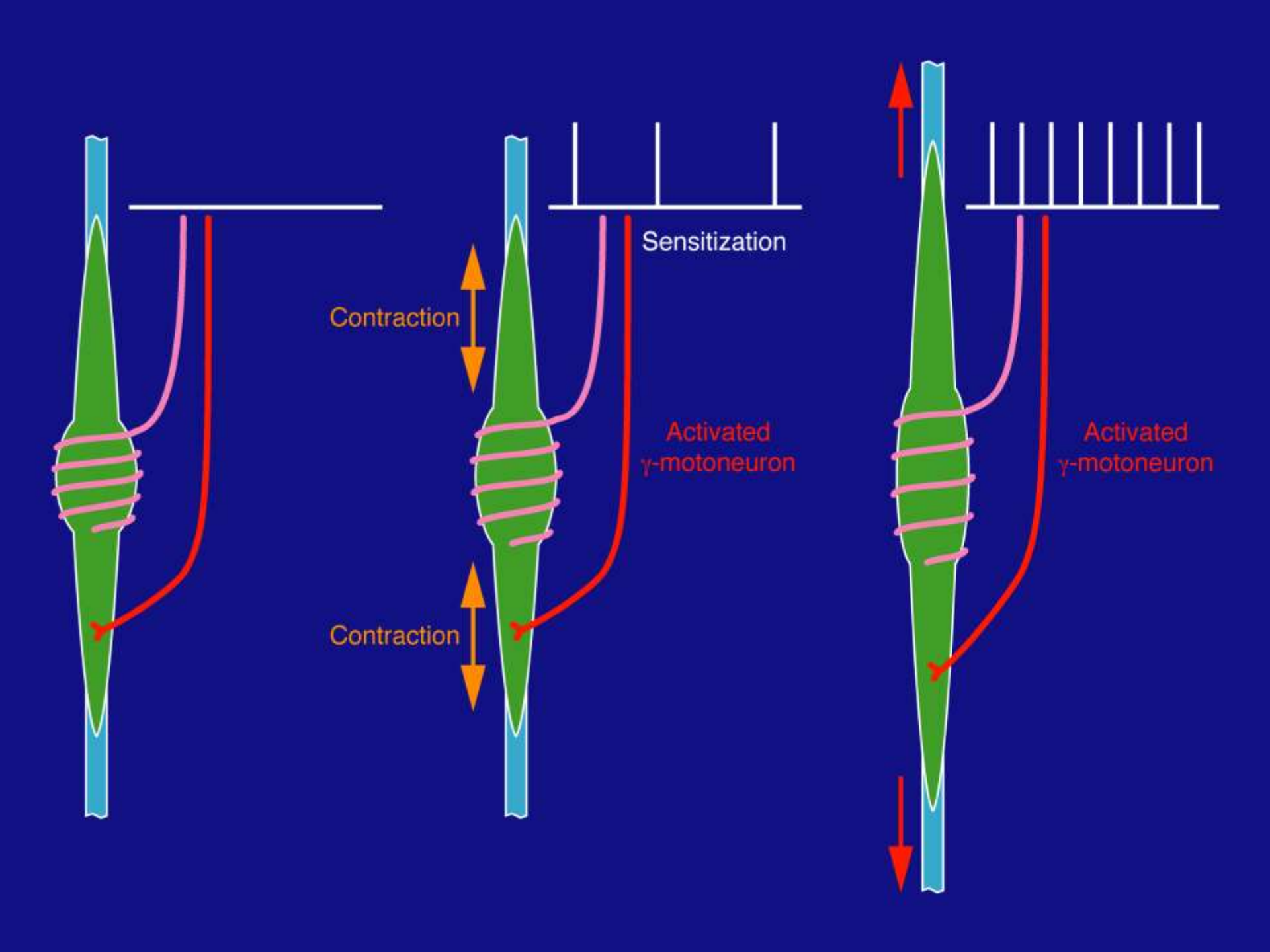

Encoding
Firing rate
Threshold stimulus
Spontaneous rate
Stimulus strength

SENSORY TRANSDUCTION

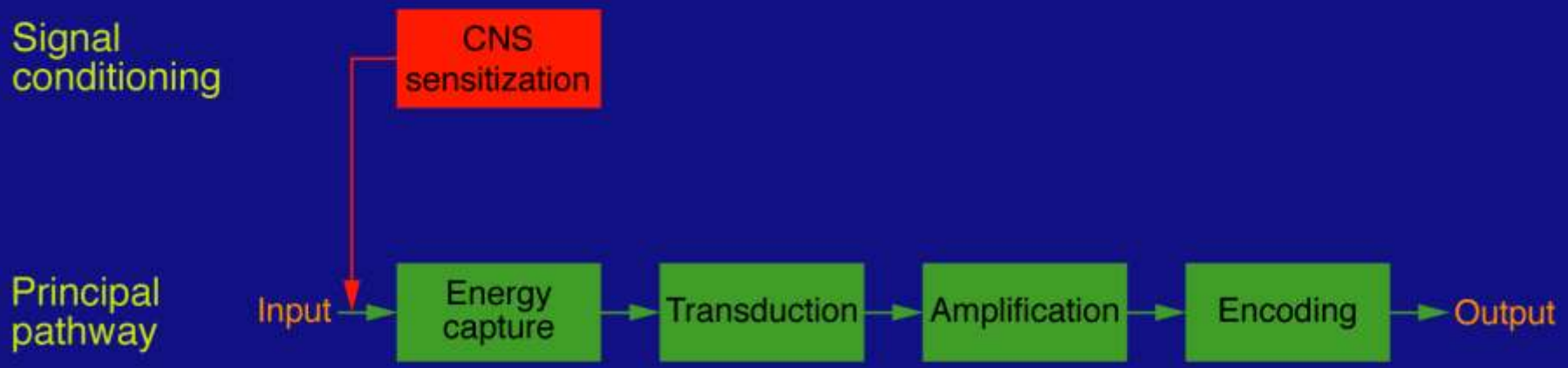

Adaptation
Relaxation
Relaxation

SENSORY TRANSDUCTION

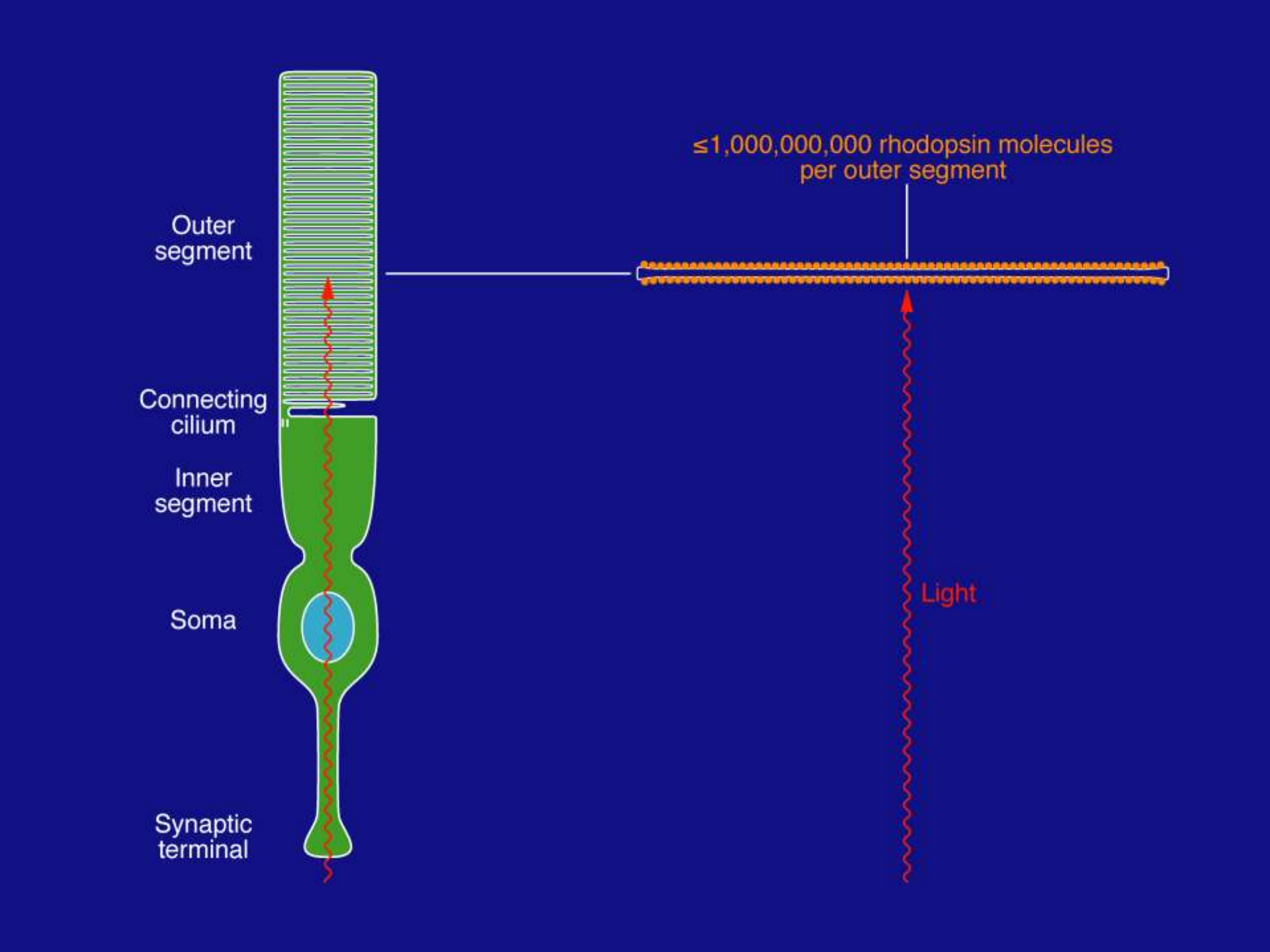


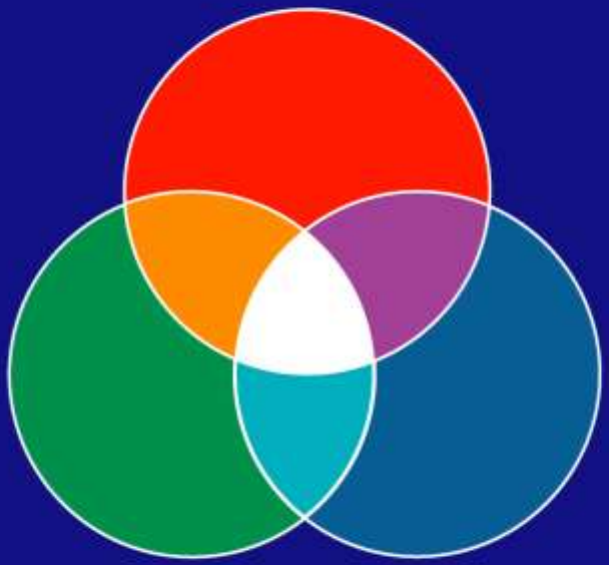

Sensitization
Contraction
Activated
γ-motoneuron
Contraction
Activated
γ-motoneuron

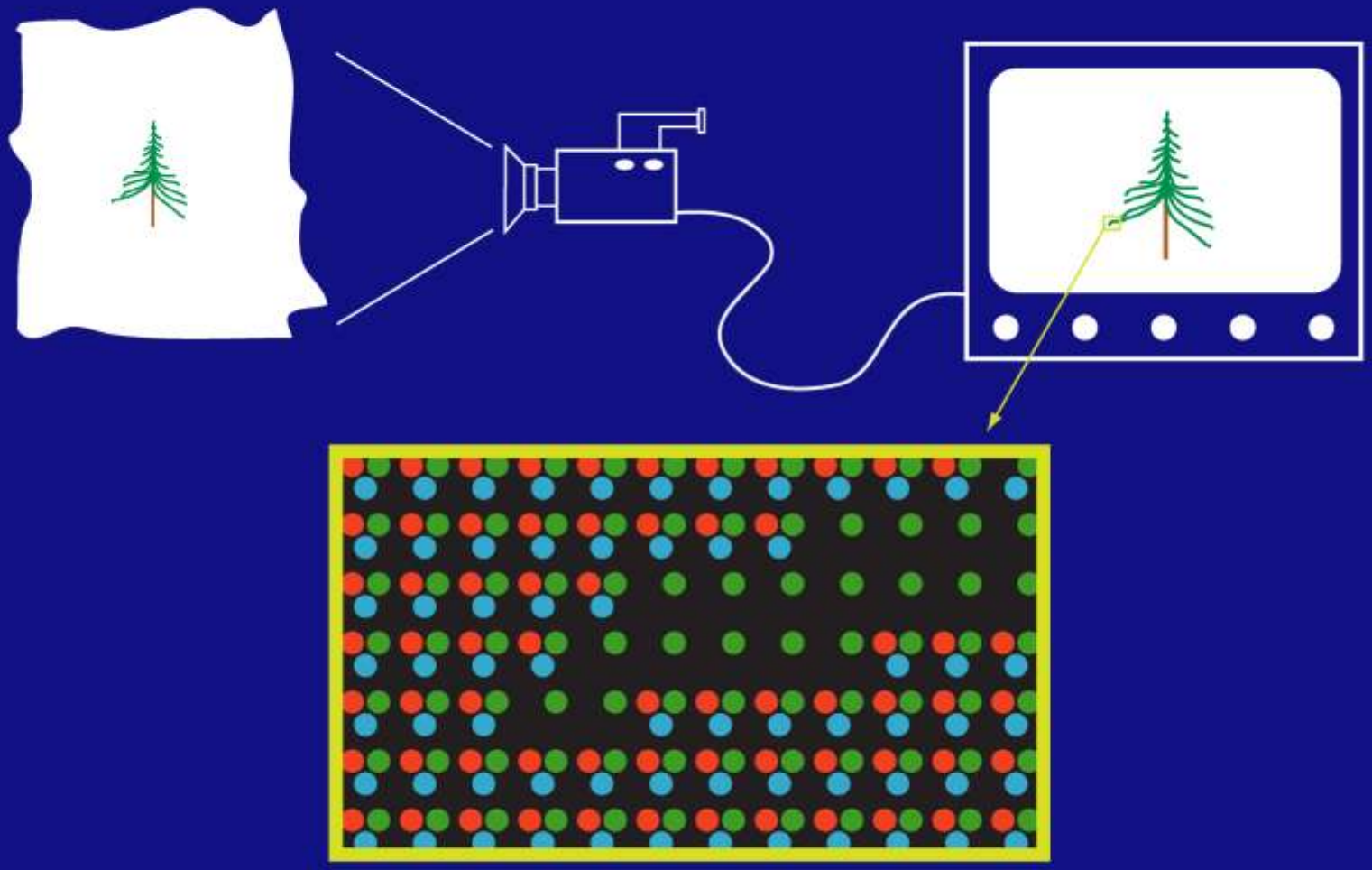
SENSORY TRANSDUCTION

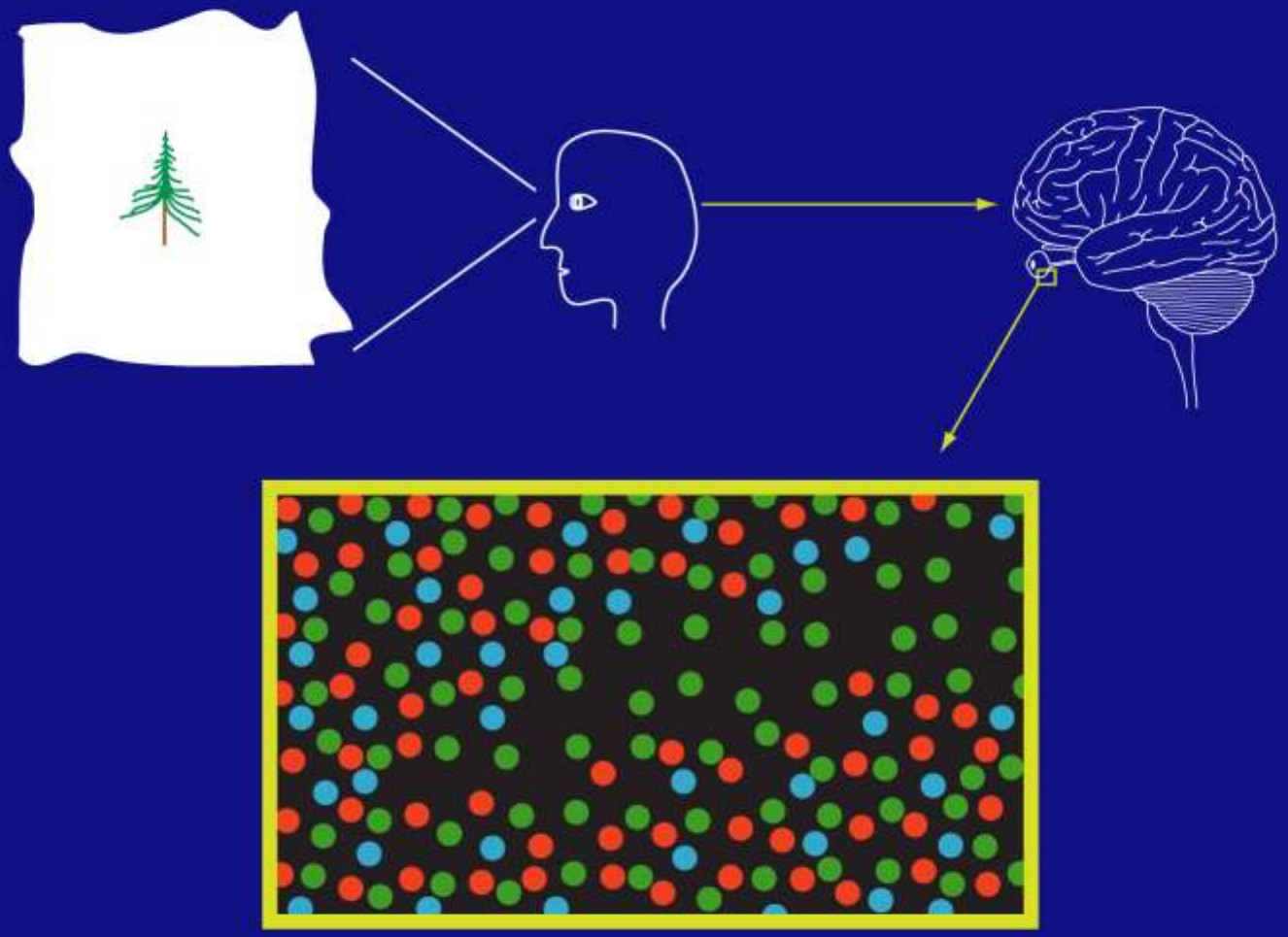


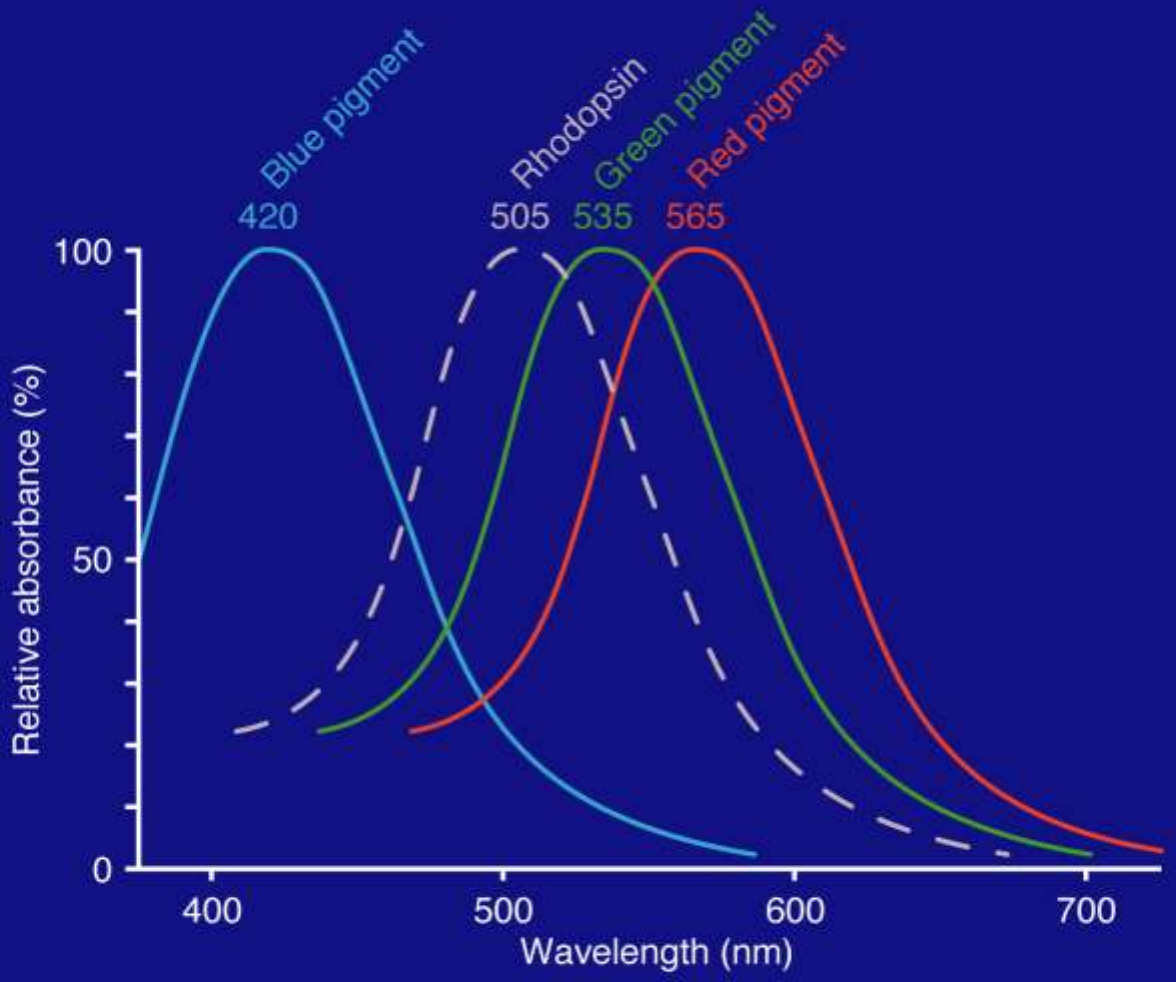
ENERGY CAPTURE
(The “antenna” function)


≤1,000,000,000 rhodopsin molecules
per outer segment
Outer
segment
Connecting
cilium
Inner
segment
Soma
Synaptic
terminal
Light

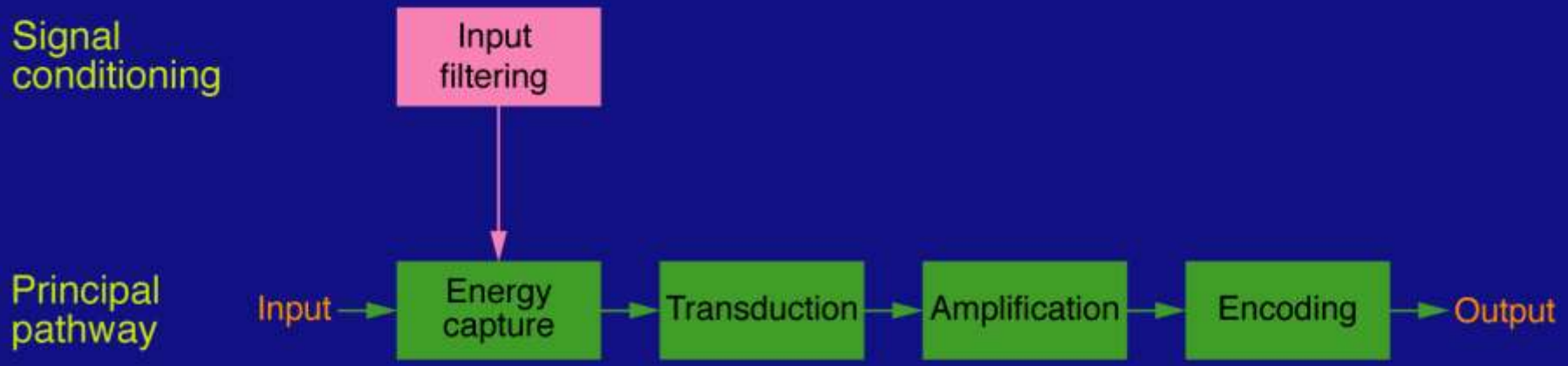


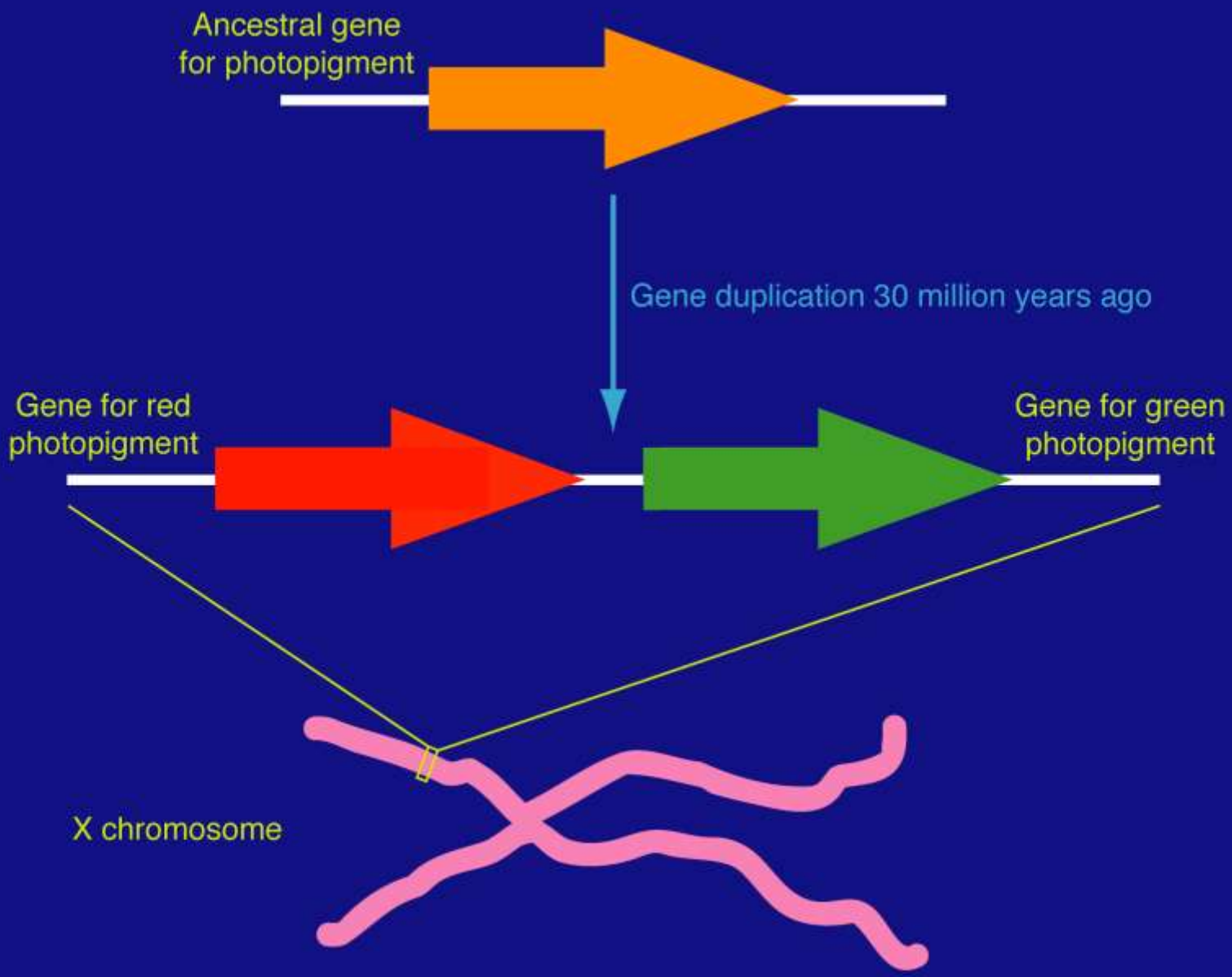


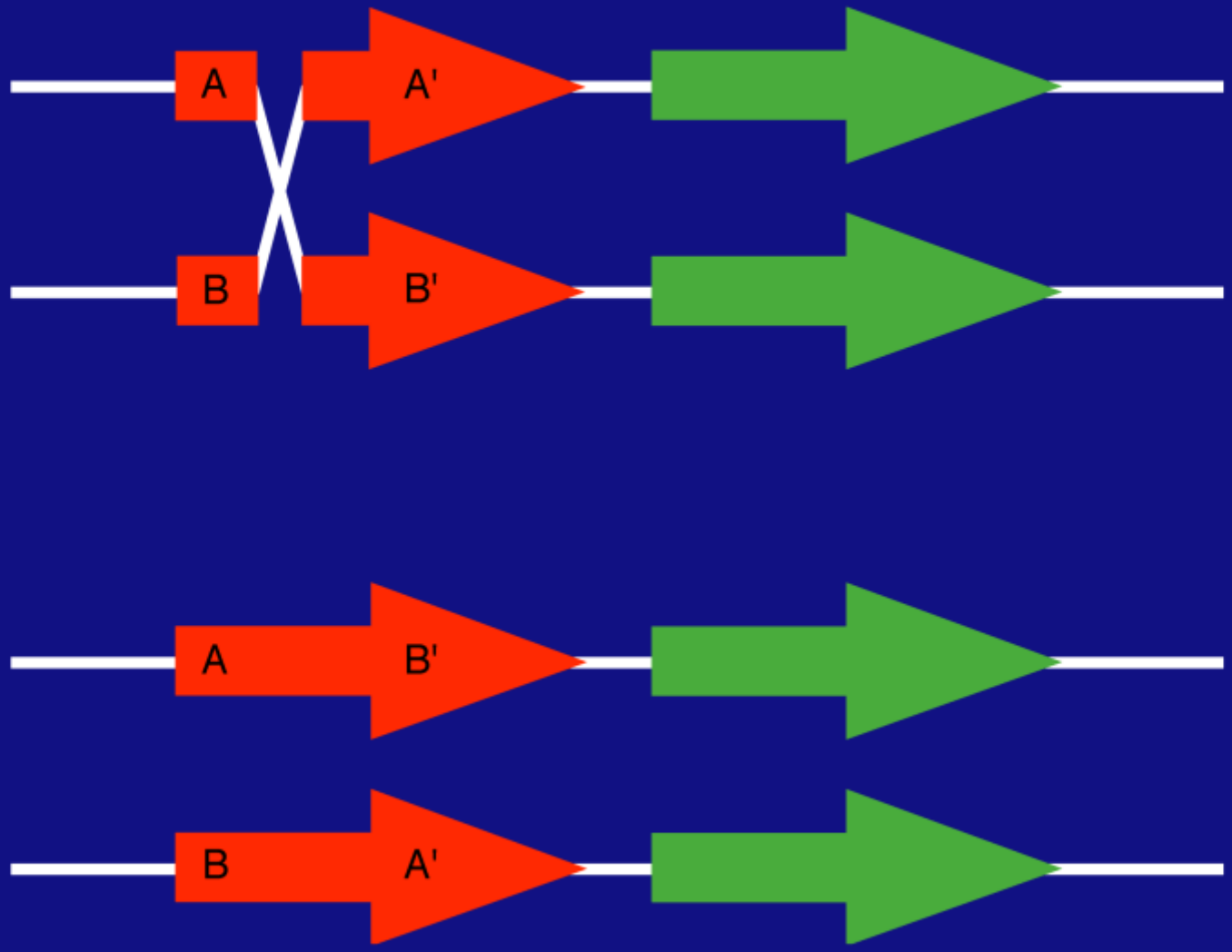


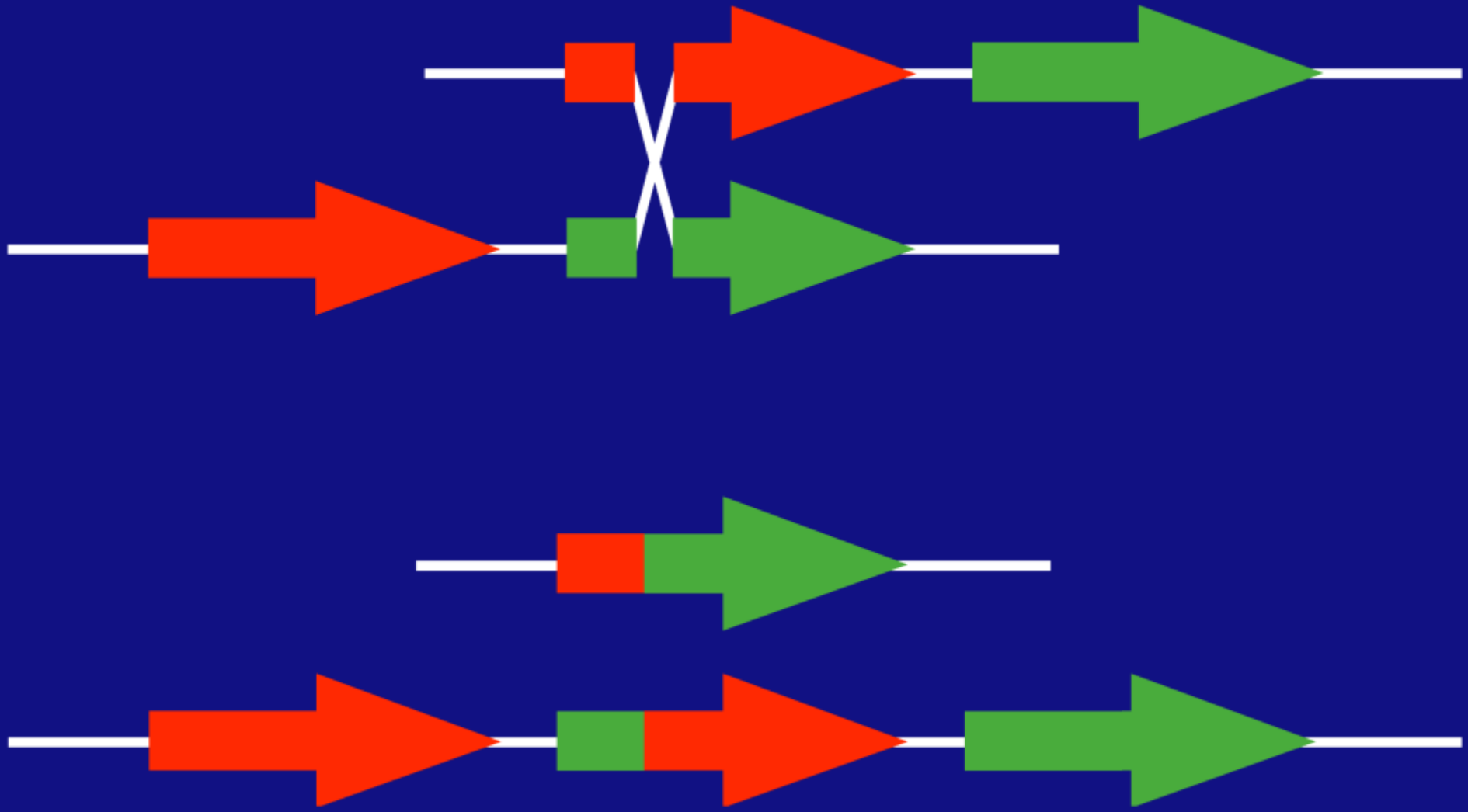

Blue pigment
420
Rhodopsin
505
Green pigment
535
Red pigment
565
100
50
0
Relative absorbance (%)
400
500
600
700
Wavelength (nm)

SENSORY TRANSDUCTION

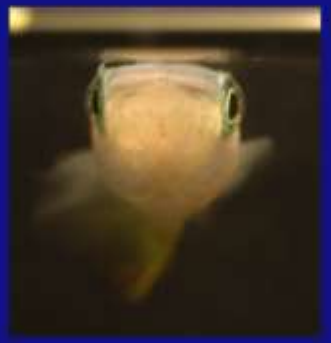



Ancestral gene
for photopigment
Gene duplication 30 million years ago
Gene for red
photopigment
Gene for green
photopigment
X chromosome

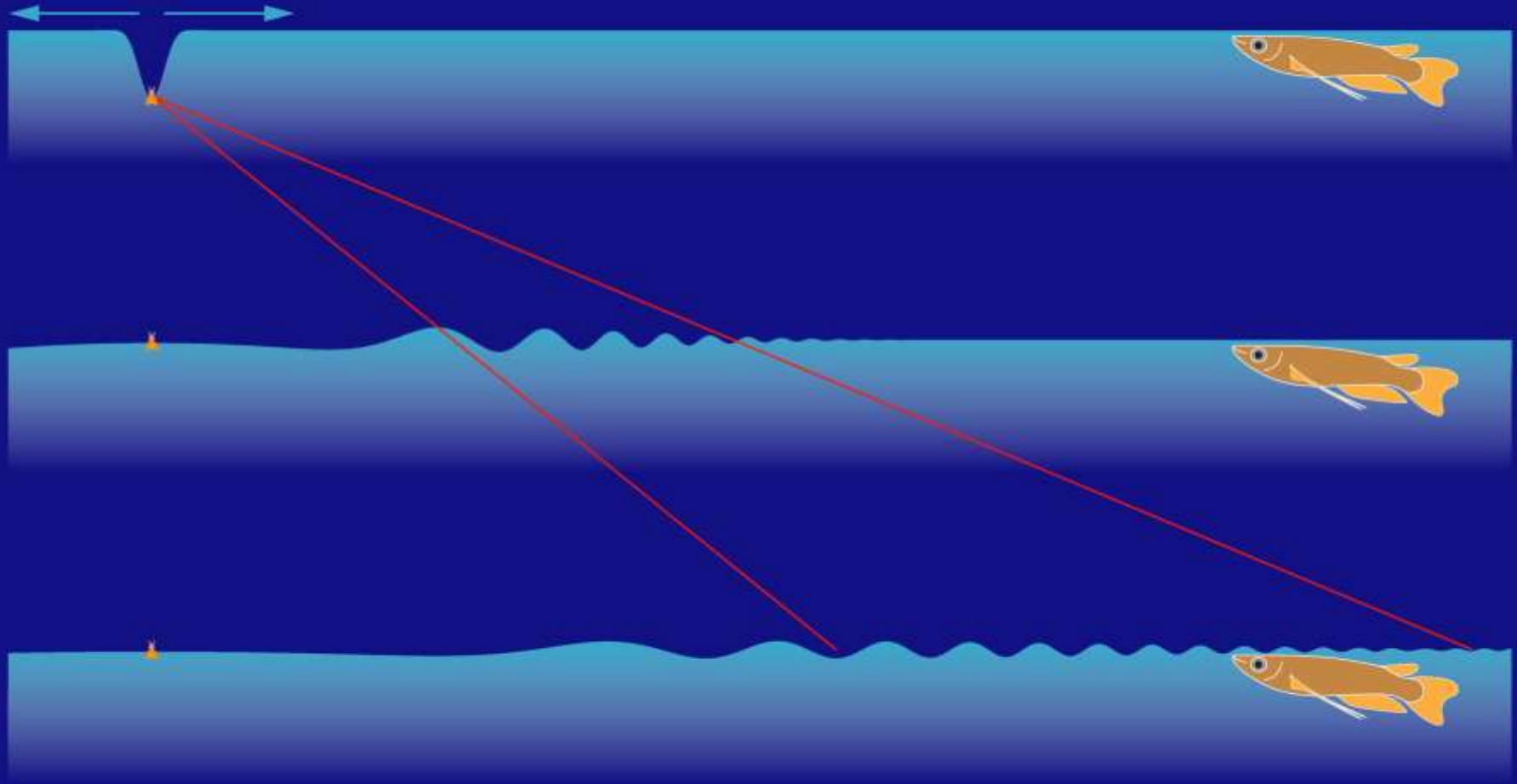

A
A'
B
B'
A
B'
B
A'

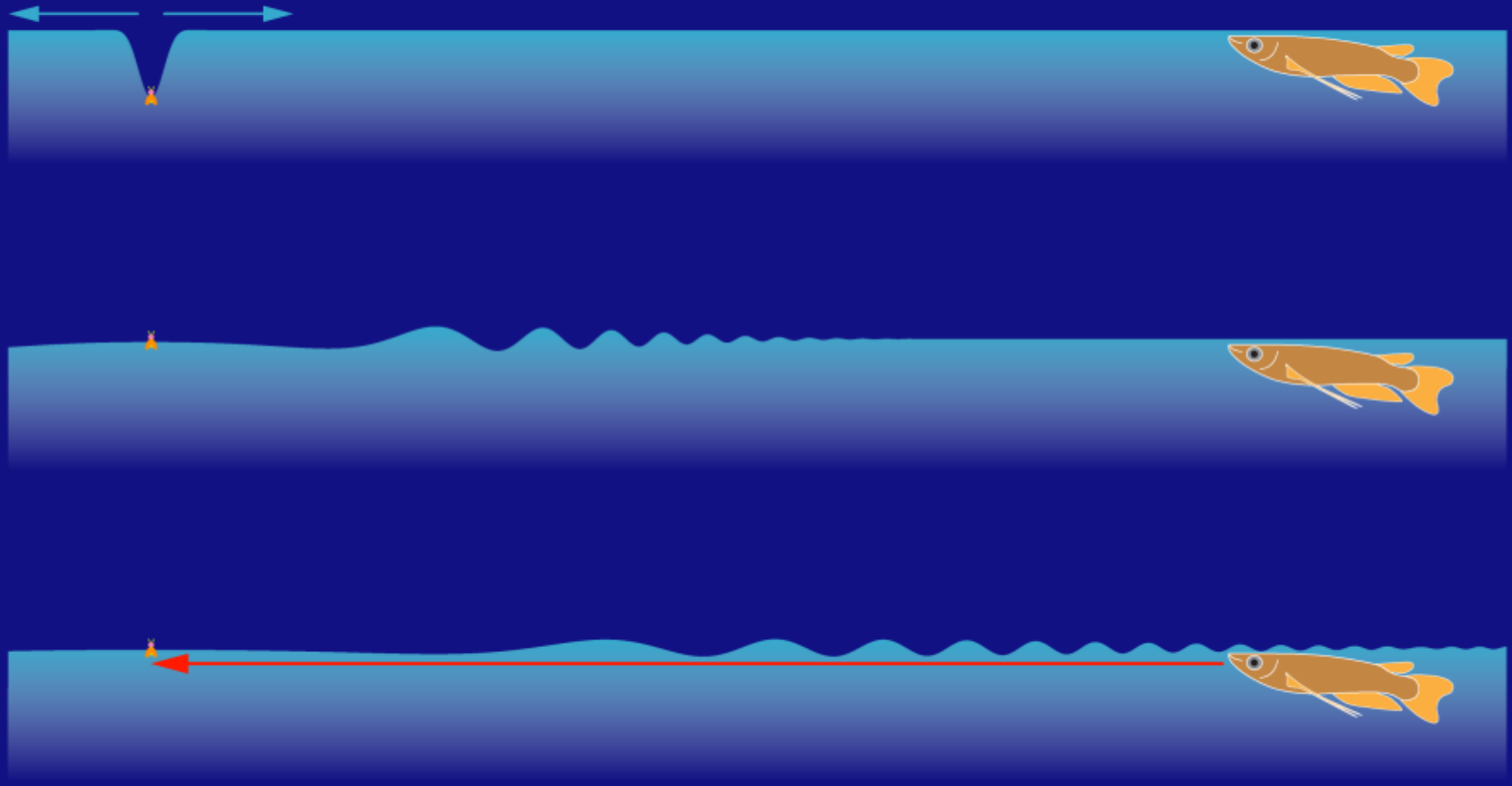


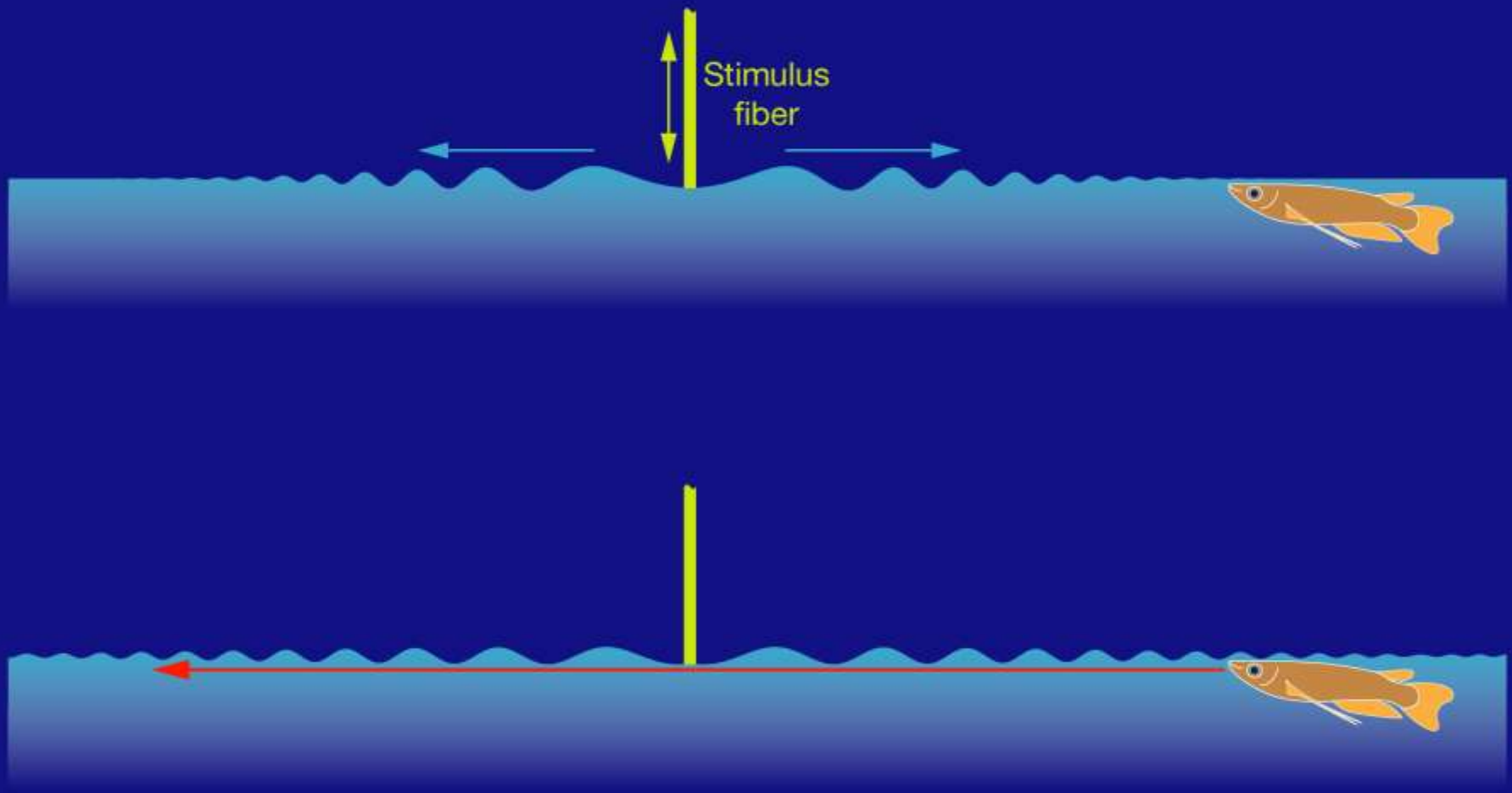
Aplocheilus lineatus

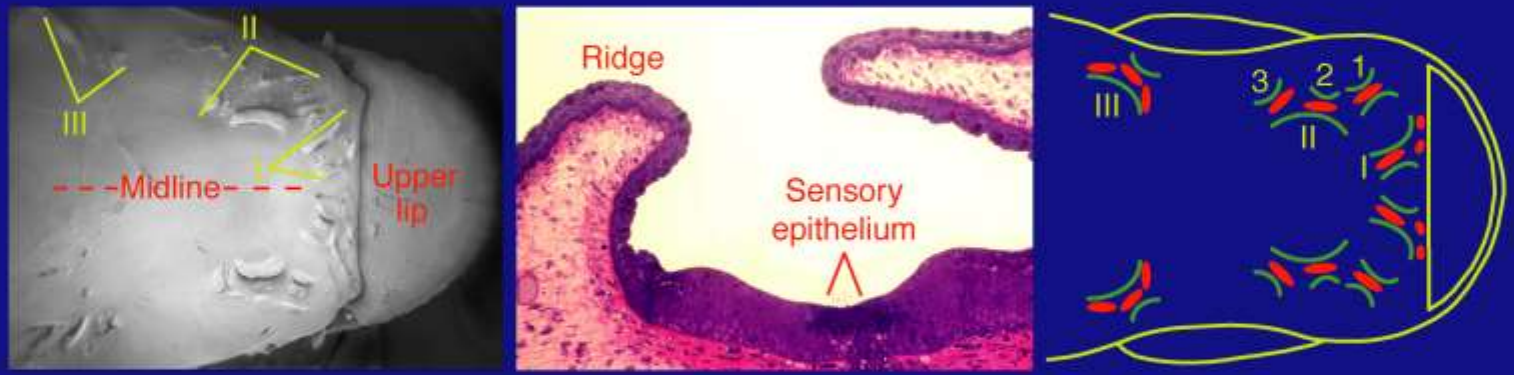


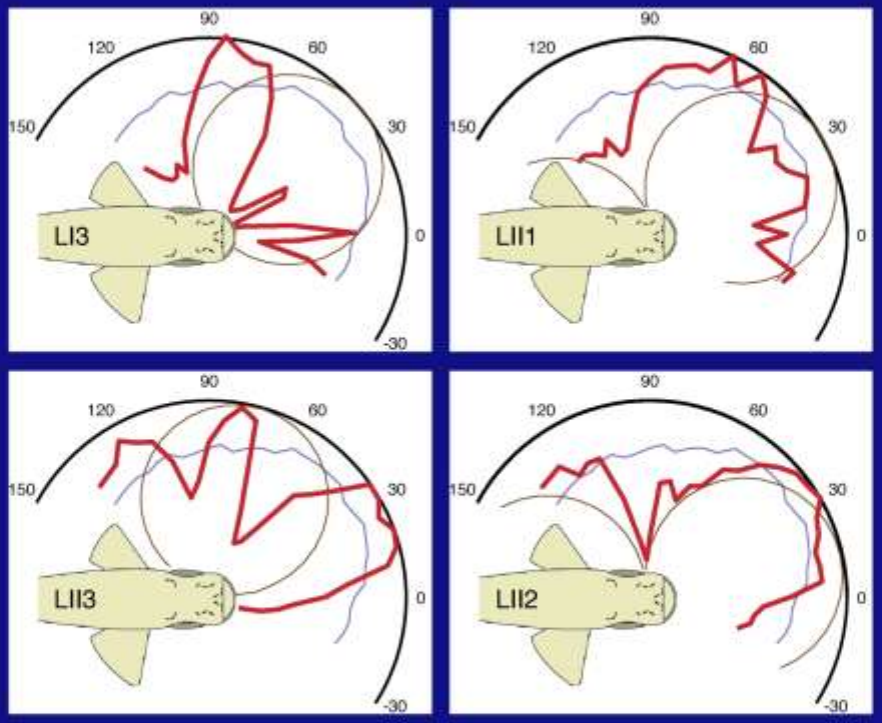
ANOMALOUS DISPERSION AND HUNTING BY *Aplocheilus*

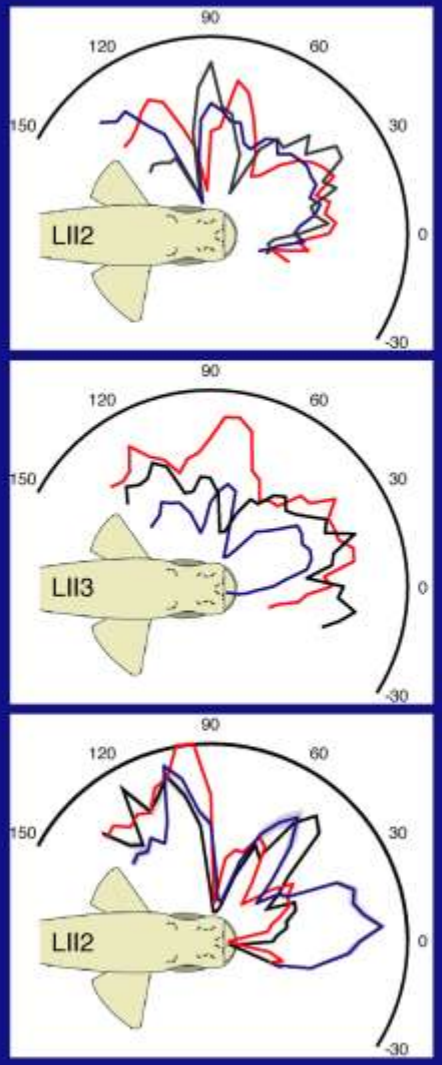


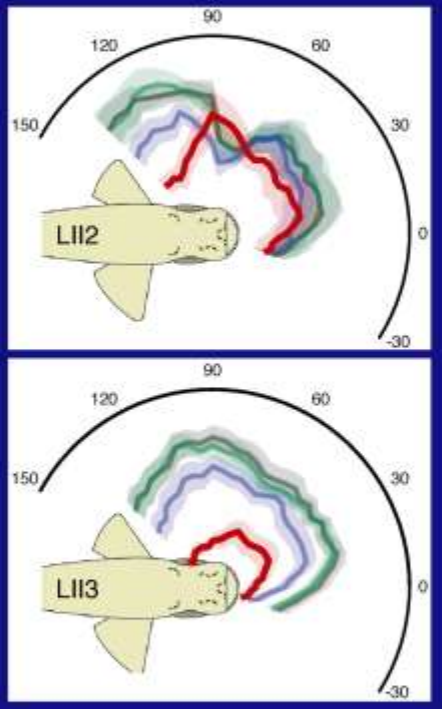



Stimulus
fiber


II
III
I
Midline
Upper lip
Ridge
Sensory epithelium
III
3
2
1
II
I

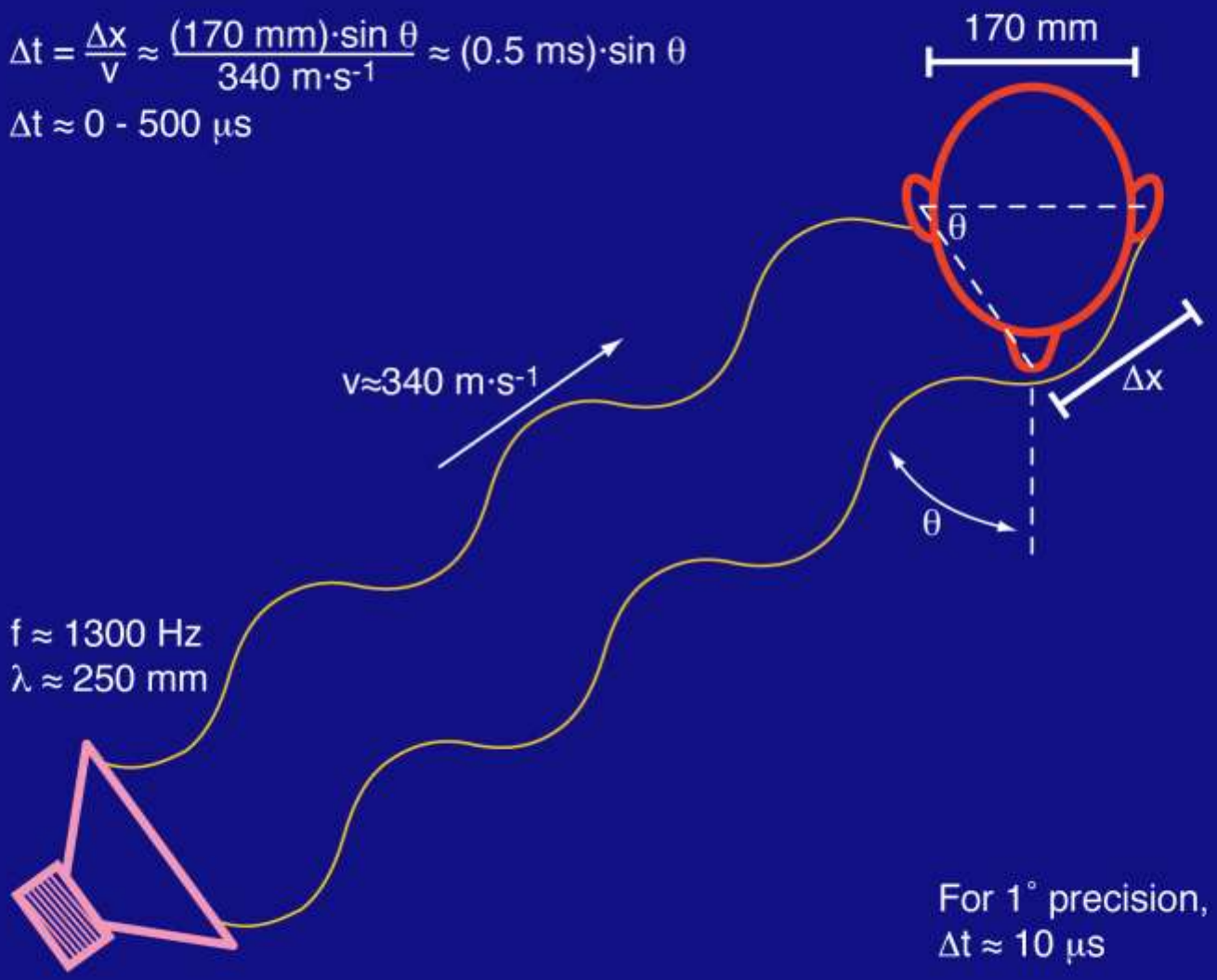

90
120
60
150
30
0
-30
LI3
LII1
LII3
LII2


90
120
60
150
30
0
-30
LII2
90
120
60
150
30
0
-30
LII3
90
120
60
150
30
0
-30
LII2

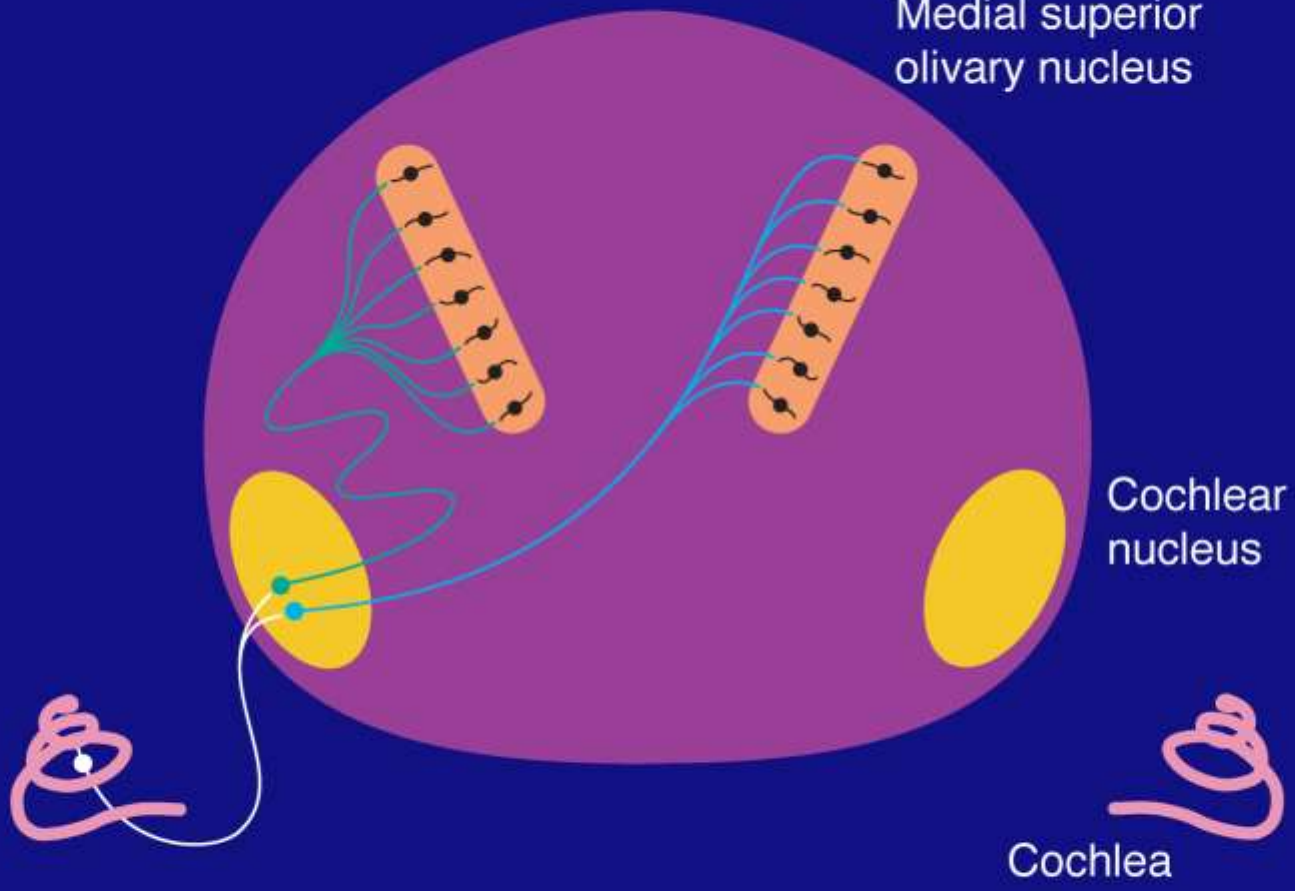

90
120
60
150
30
0
-30
LII2
90
120
60
150
30
0
-30
LII3

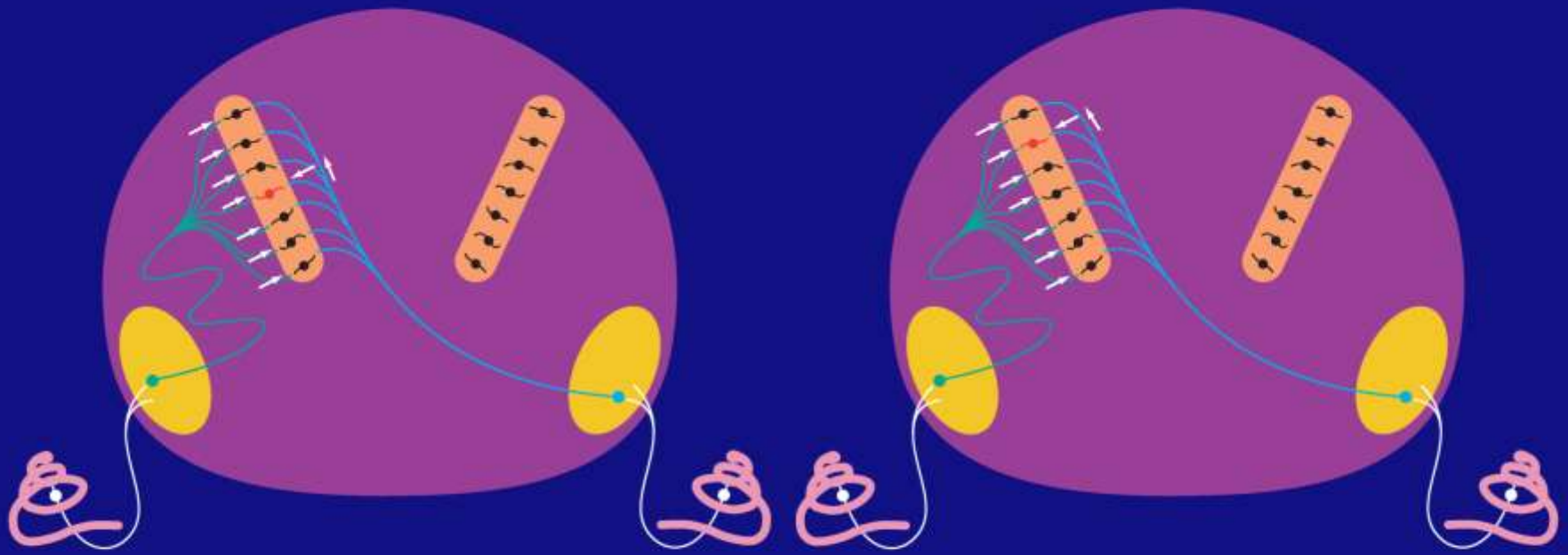
$$\Delta t = \frac{\Delta x}{v} \approx \frac{(170\ \text{mm})\cdot\sin\theta}{340\ \text{m}\cdot\text{s}^{-1}} \approx (0.5\ \text{ms})\cdot\sin\theta$$

$\Delta t \approx 0 - 500\ \mu s$



For 1° precision,
$\Delta t \approx 10\ \mu s$

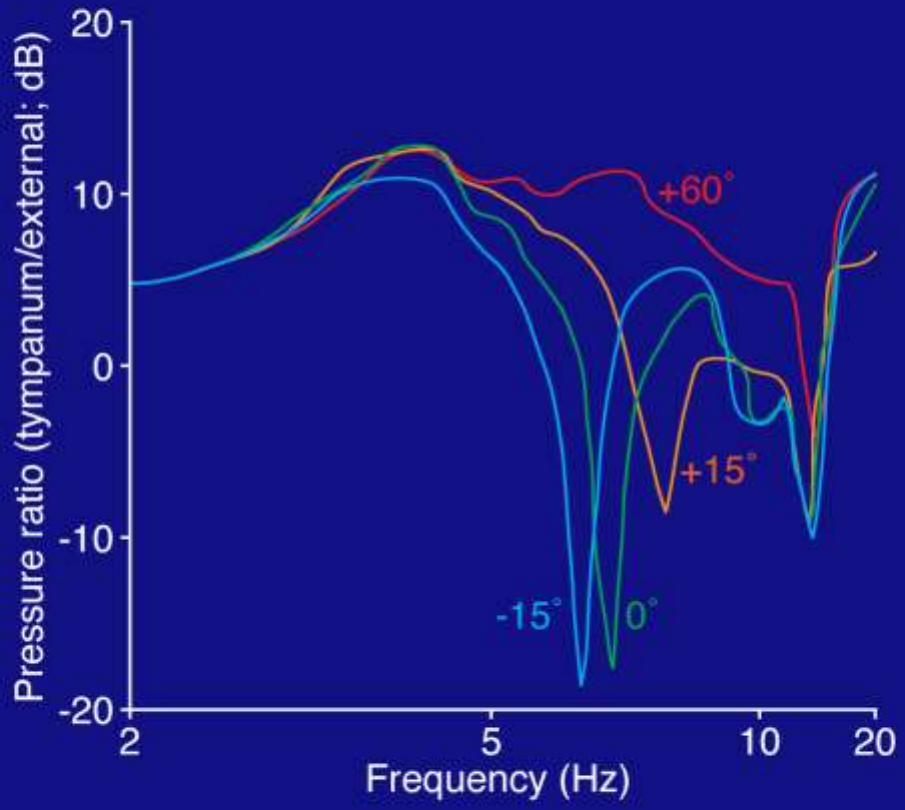

Medial superior
olivary nucleus
Cochlear
nucleus
Cochlea



Sound source
directly ahead

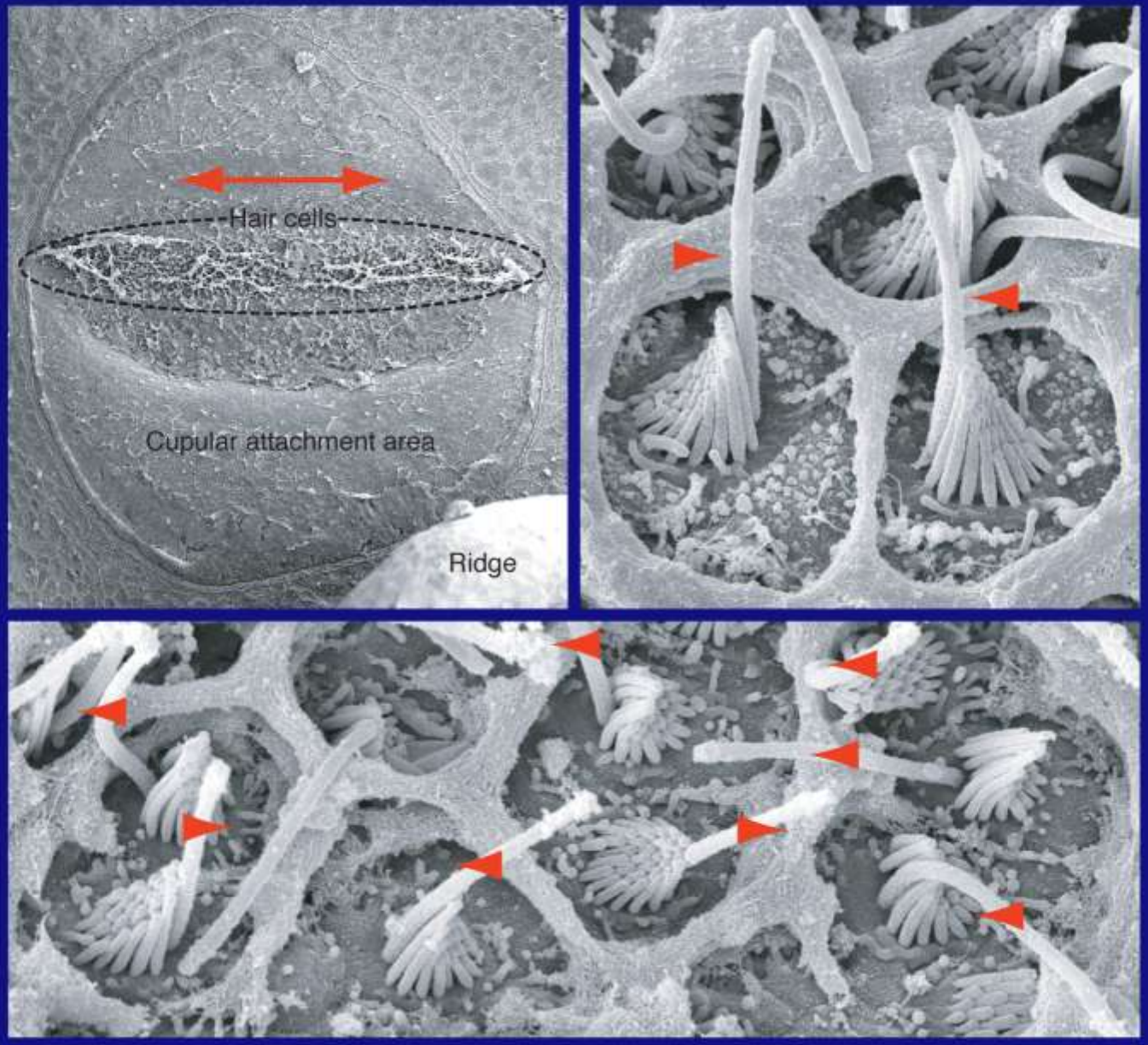
Sound source
to observer's right

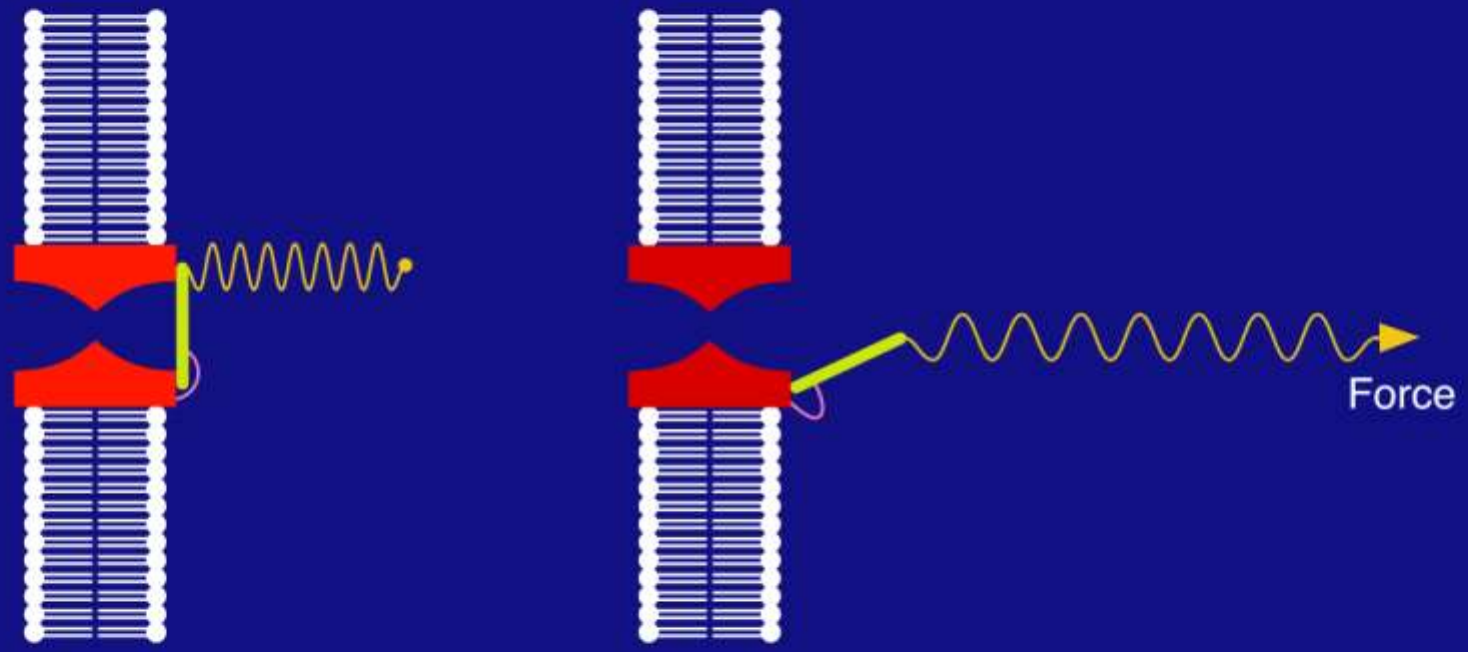
EFFECT OF SOUND – SOURCE ELEVATION ON INTENSITY AT THE TYMPANUM

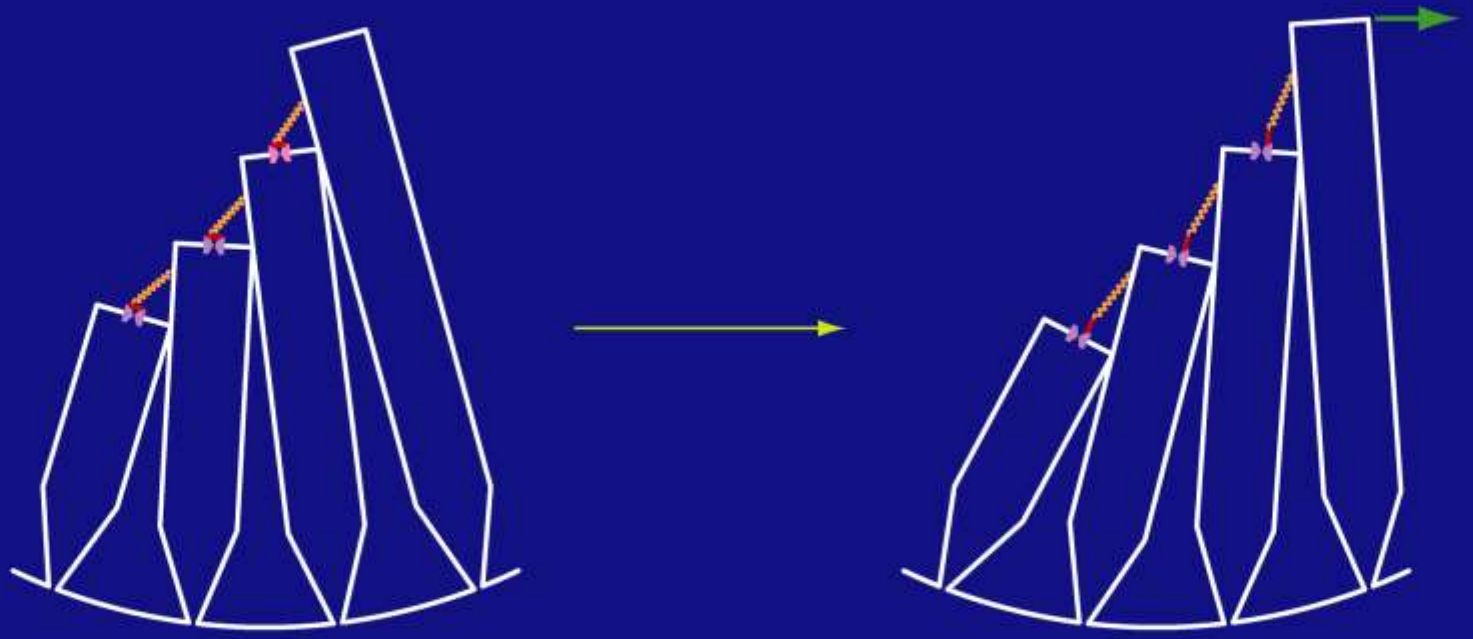


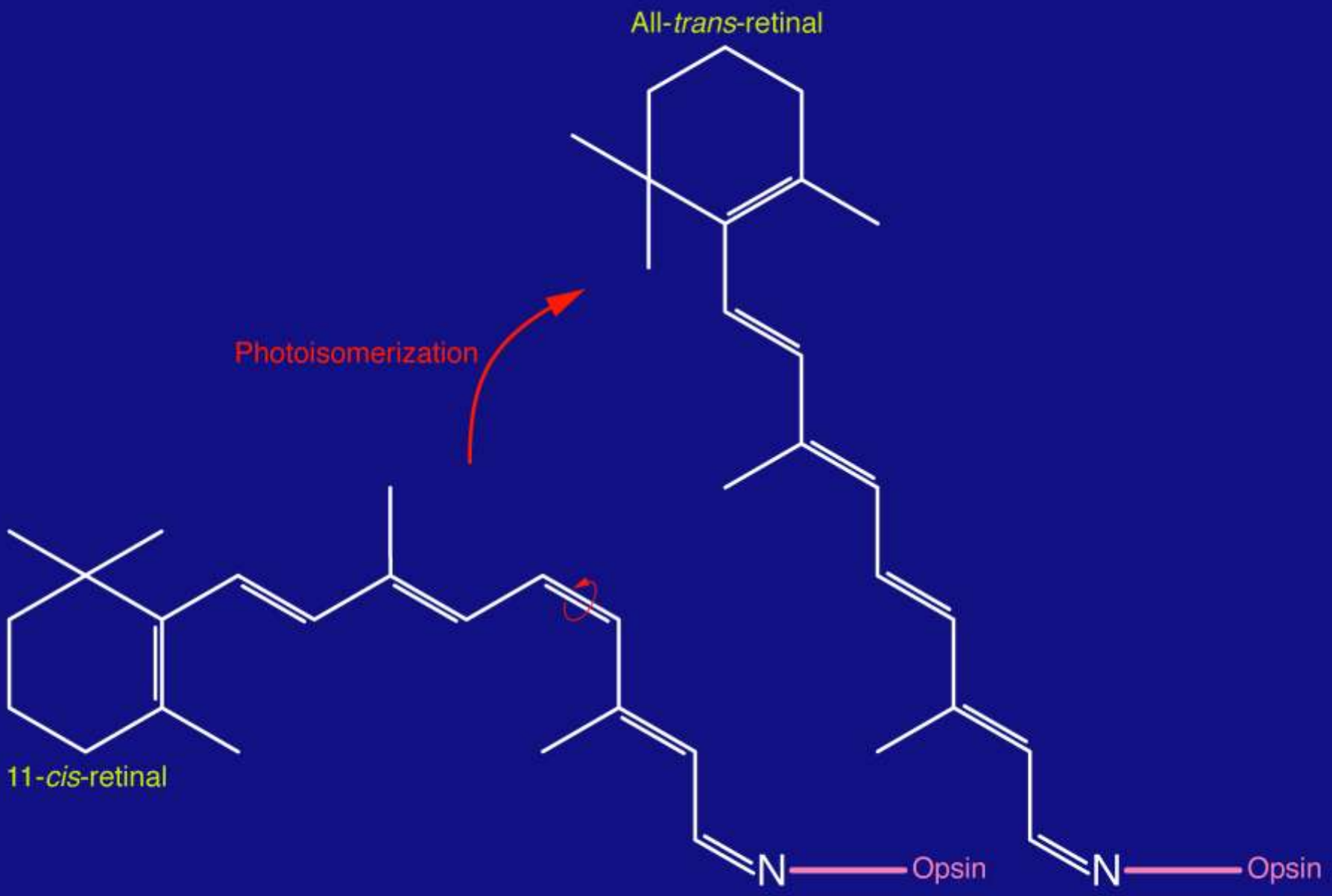
After Shaw (1974)

TRANSDUCTION
(interconverting forms of energy)

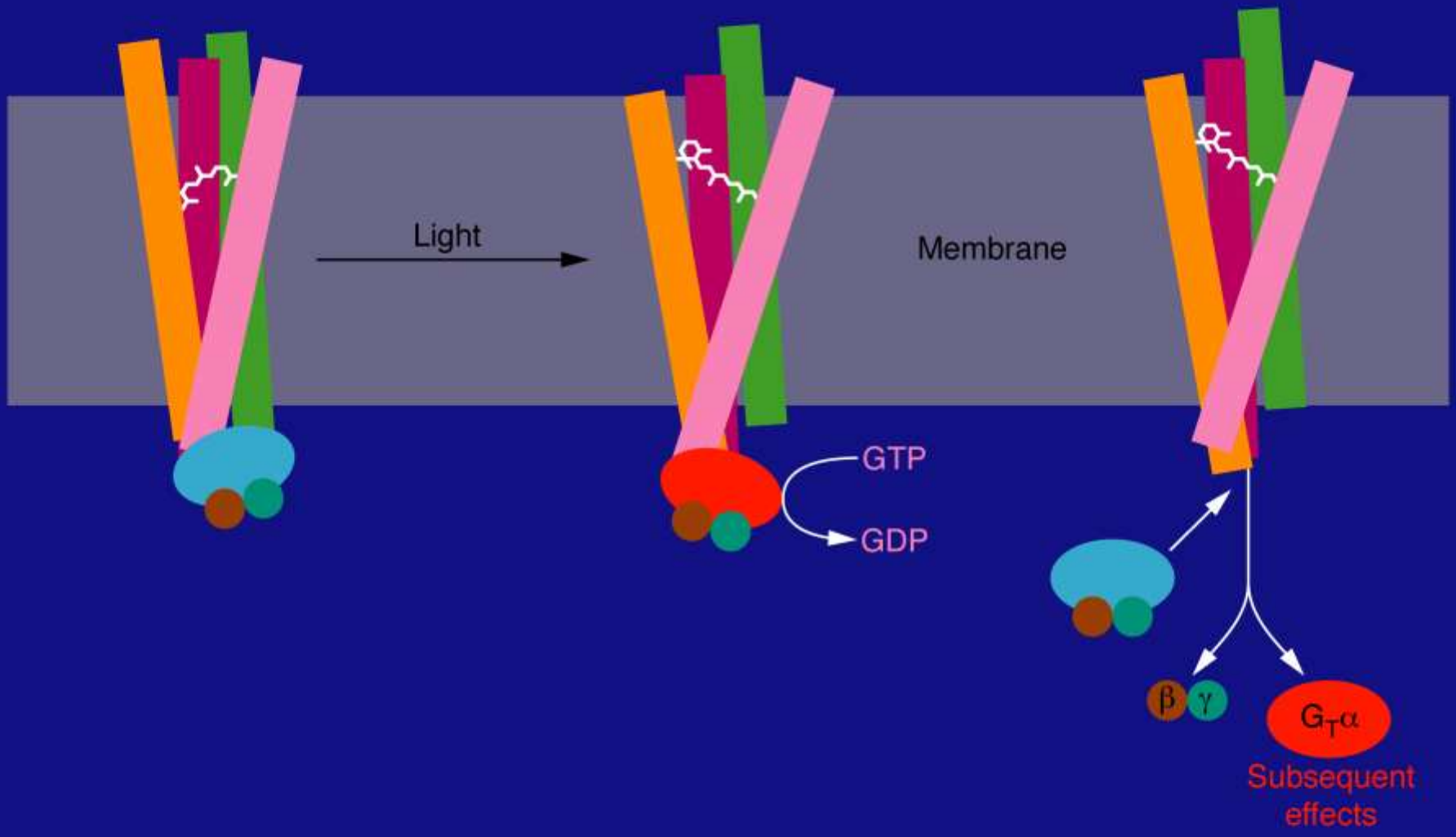

Hair cells
Cupular attachment area
Ridge

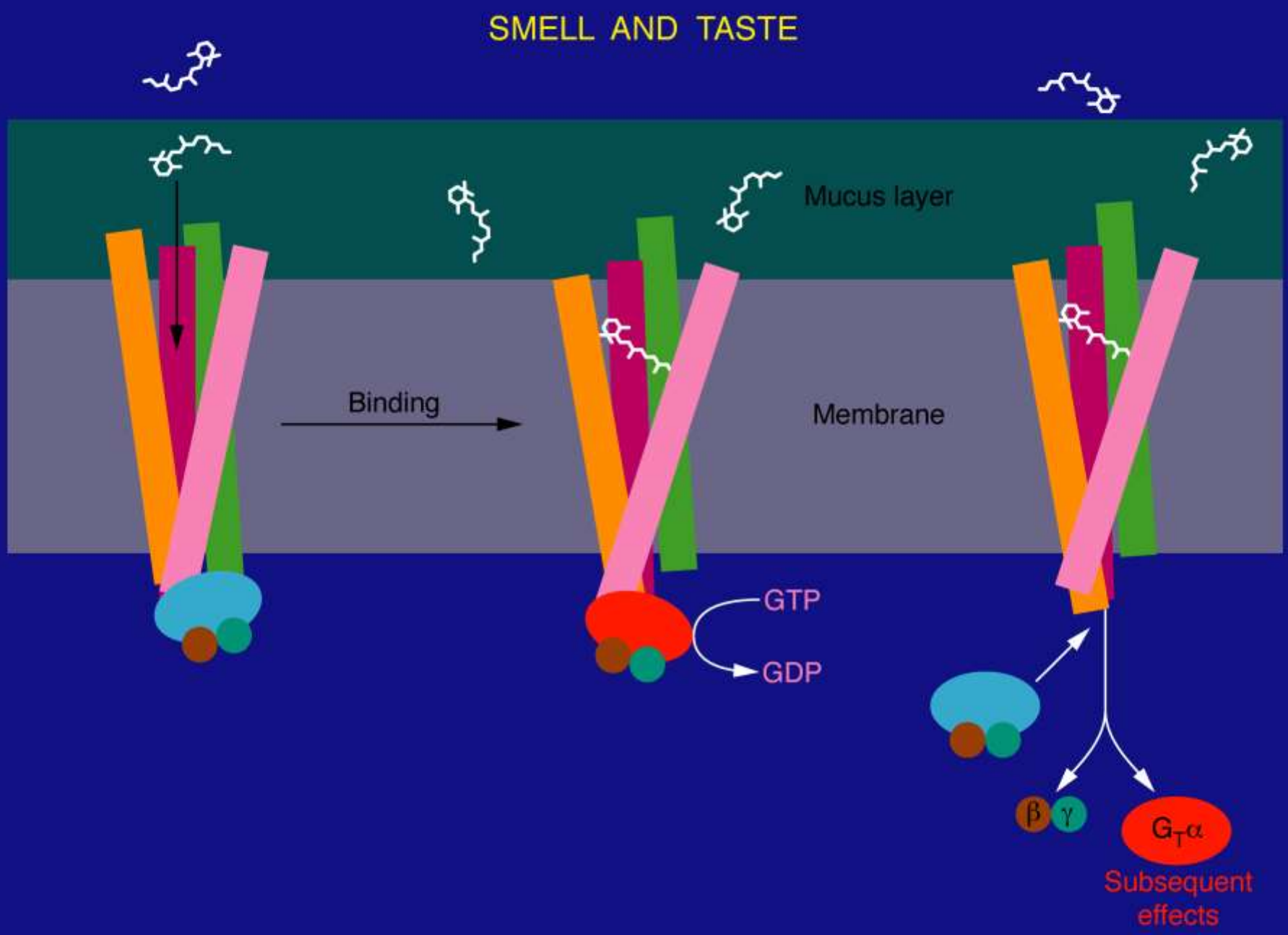

Force



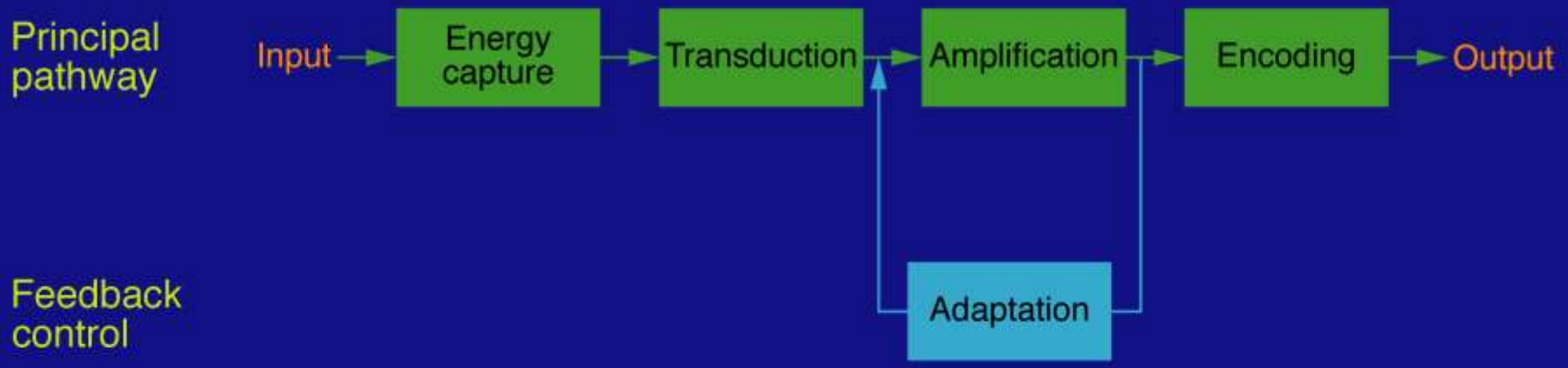

All-*trans*-retinal
Photoisomerization
11-*cis*-retinal
N
Opsin
N
Opsin

ACTIVATION OF RHODOPSIN




SMELL AND TASTE
Mucus layer
Binding
Membrane
GTP
GDP
β
γ
$G_T\alpha$
Subsequent effects

SENSORY TRANSDUCTION



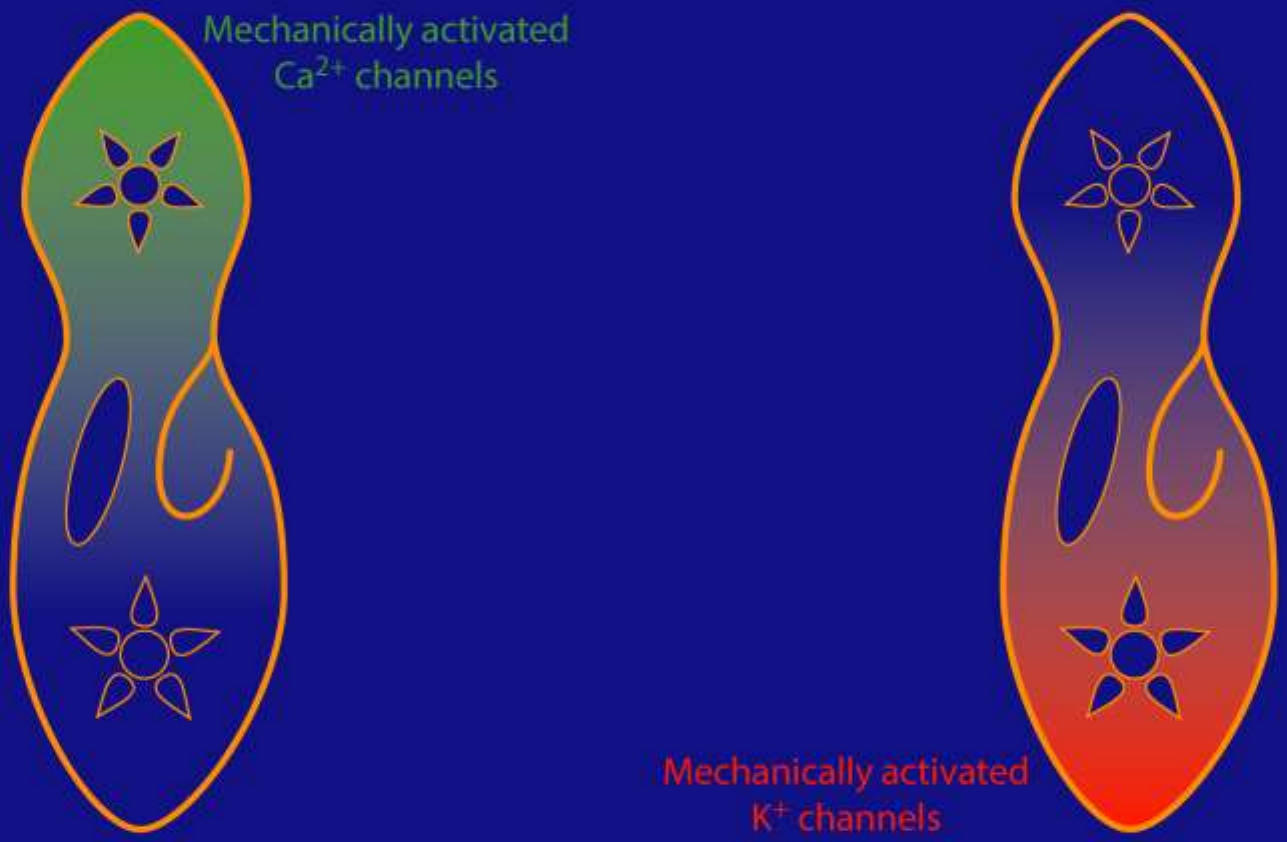
AMPLIFICATION
(ionic and metabolic)

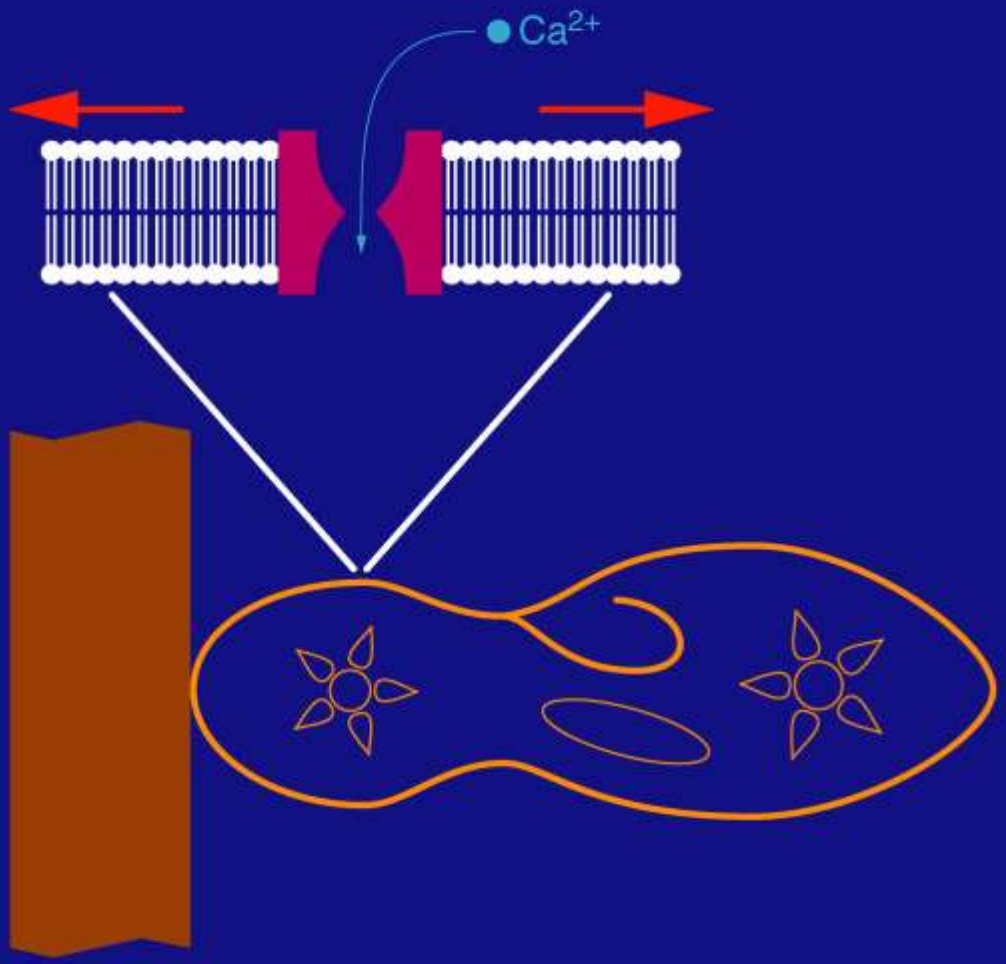
LOCOMOTORY RESPONSES OF CILIATES

Free swimming

Obstacle avoidance

Predator evasion


Mechanically activated
Ca^{2+} channels
Mechanically activated
K^{+} channels



Input work (channel expansion):

$$W_{in} = kX^2/2 \approx (1\ \text{mN}\cdot\text{m}^{-1})(5\ \text{nm})^2/2$$
$$\approx 12\ \text{zJ}\ (3\ k_B T)$$

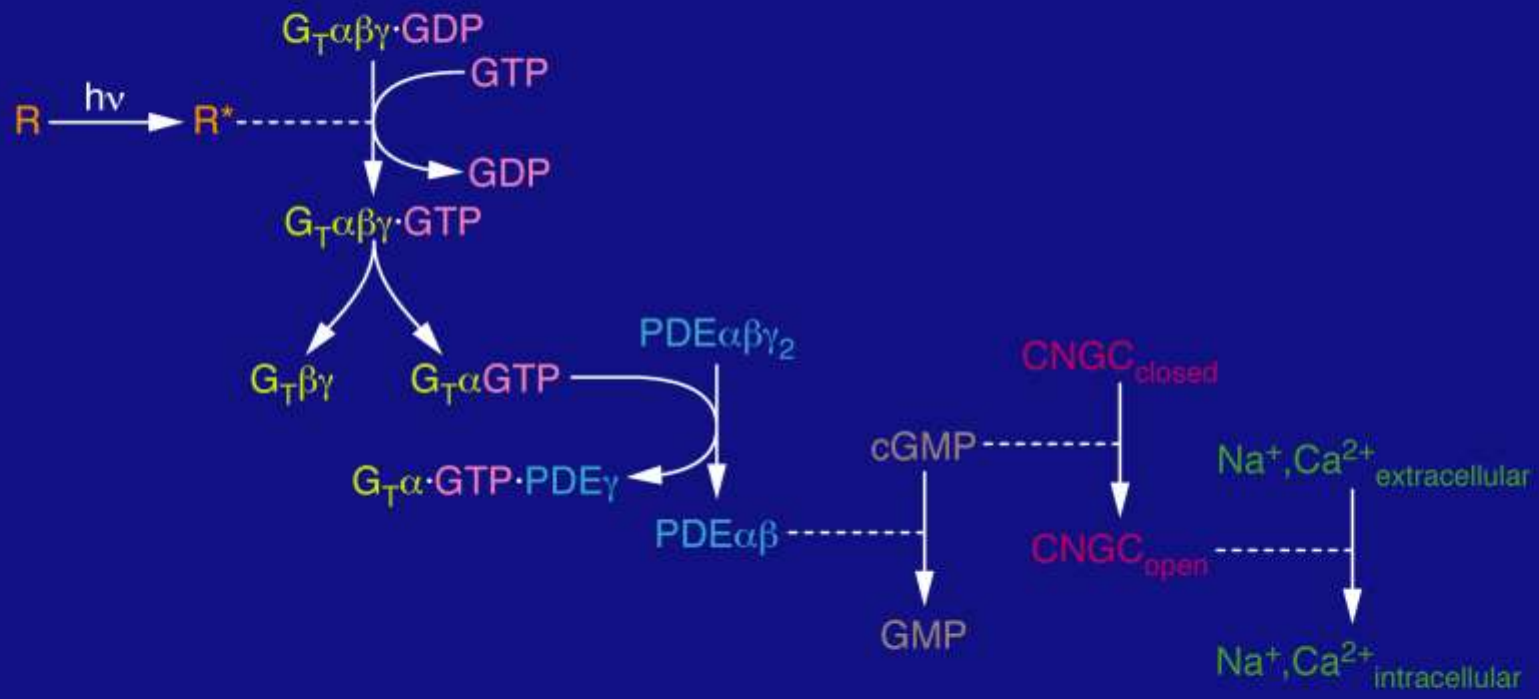
Output energy (electrical signal):

$$Q = It \approx (5\ \text{pA})(100\ \text{ms})$$
$$\approx 500\ \text{fC}$$

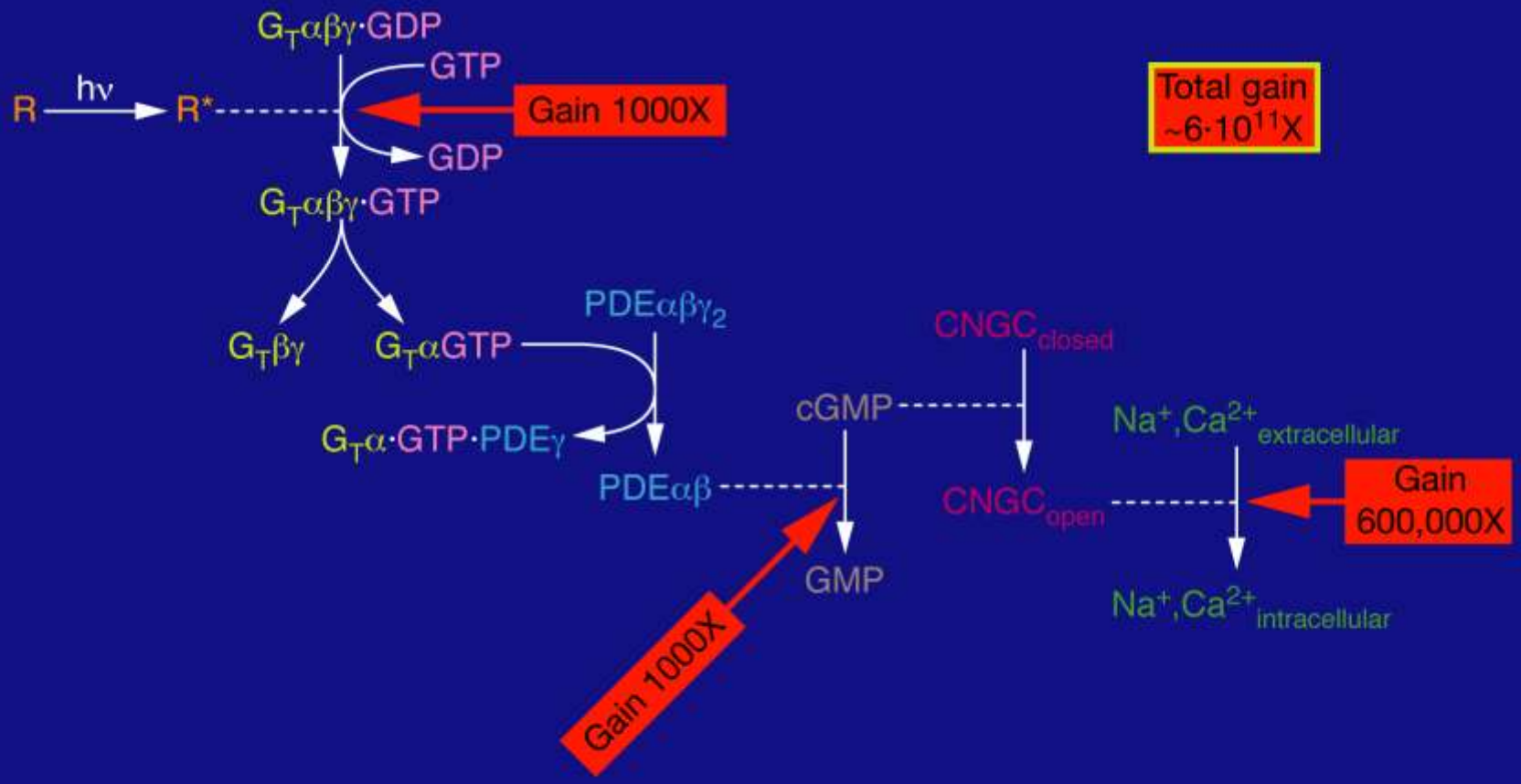
$$E_{out} = QV_M$$
$$\approx (500\ \text{fC})(50\ \text{mV})$$
$$\approx 25\ \text{fJ}\ (6{,}000{,}000\ k_B T)$$

Gain: ~2,000,000X

THE PHOTORECEPTOR SIGNALING CASCADE

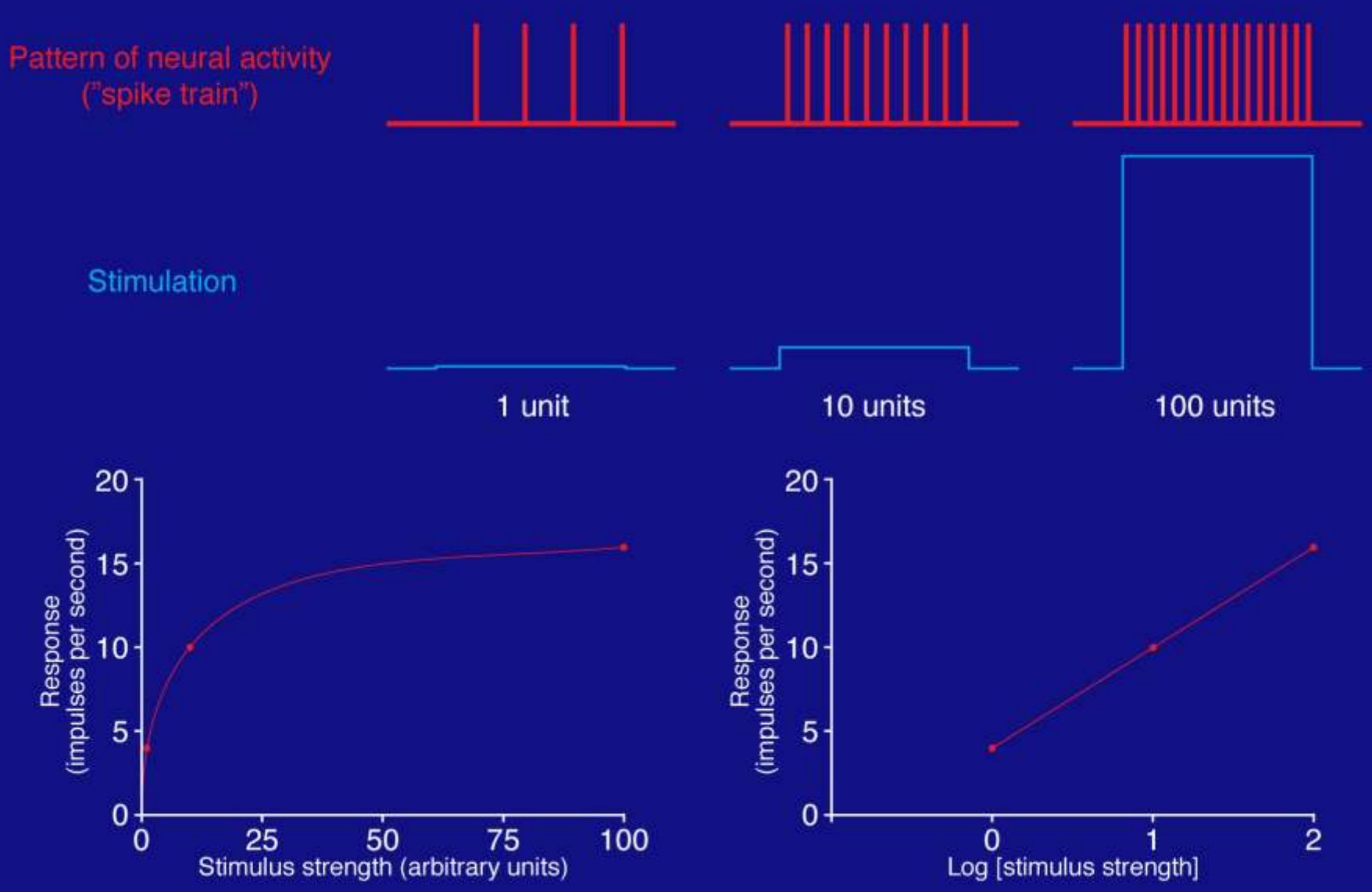


THE PHOTORECEPTOR SIGNALING CASCADE



ENCODING
(representing stimuli as nerve impulses)

NEURAL RATE CODING



THE WEBER – FECHNER RELATION

The perceived difference ΔR in the response to an increment ΔS in a stimulus is inversely proportional to the magnitude S of the stimulus:

$$\Delta R = k \frac{\Delta S}{S}$$

Integrating this relation,

$$R = k \cdot \ln(S) + \text{constant}$$

The integration constant reflects the threshold stimulus S_T:

$$R = k \cdot \ln\left(\frac{S}{S_T}\right)$$