FERTILIZATION

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CONCEPT AND TYPES

- The process of fusion of sperm with egg (ovum) to produce a zygote is called fertilization.
- It is the crucial and primary stage of sexual reproduction.
- During sexual intercourse, the penis ejaculates millions of sperm into the vagina of the woman.
- Sperms will travel through the uterus to the oviducts.
- At the oviduct, one out of million sperm fertilizes the released ovum.
- The fertilized egg develops into a zygote. Without the fusion of gametes, sexual reproduction is futile.
- It doesn't occur in asexual reproduction.
- Fertilization in most animals is similar to that in humans.
- Animals also produce gametes for fusion.
- But the fusion of gametes may take place inside or outside the body. Based on this, fertilization is of two types – internal and external fertilization.

TYPES OF FERTILIZATION

Internal Fertilization

- In sexual reproduction, the male inserts the semen into the female reproductive tract to fuse with the egg. If the fusion takes place within the female parent, it is called internal fertilization. In humans and most animals like cats, lions, pigs, dogs, hens, etc., the fusion of gametes takes place internally. In this type, a zygote is formed within the mother and gets its nourishment from her.

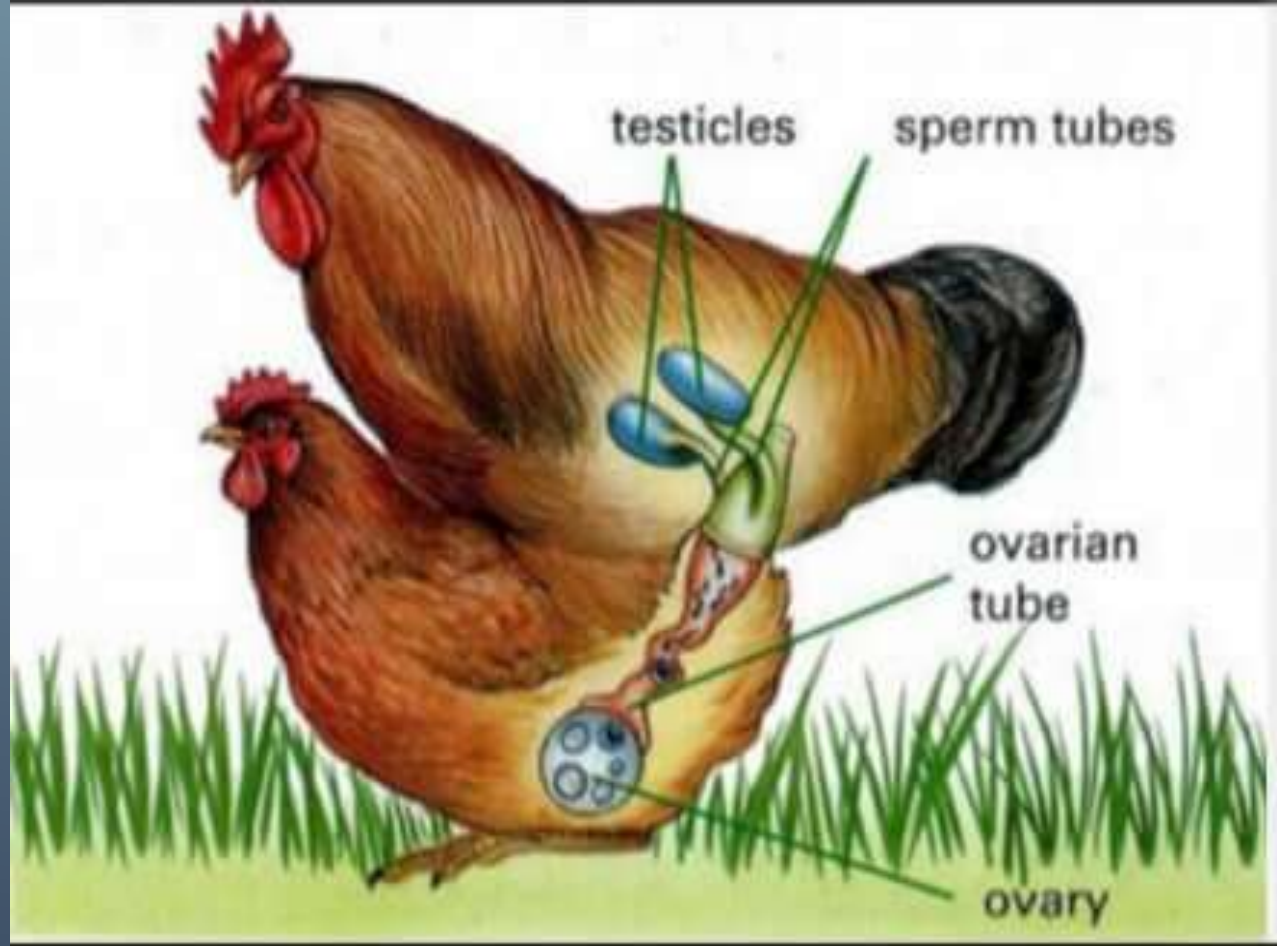
External Fertilization

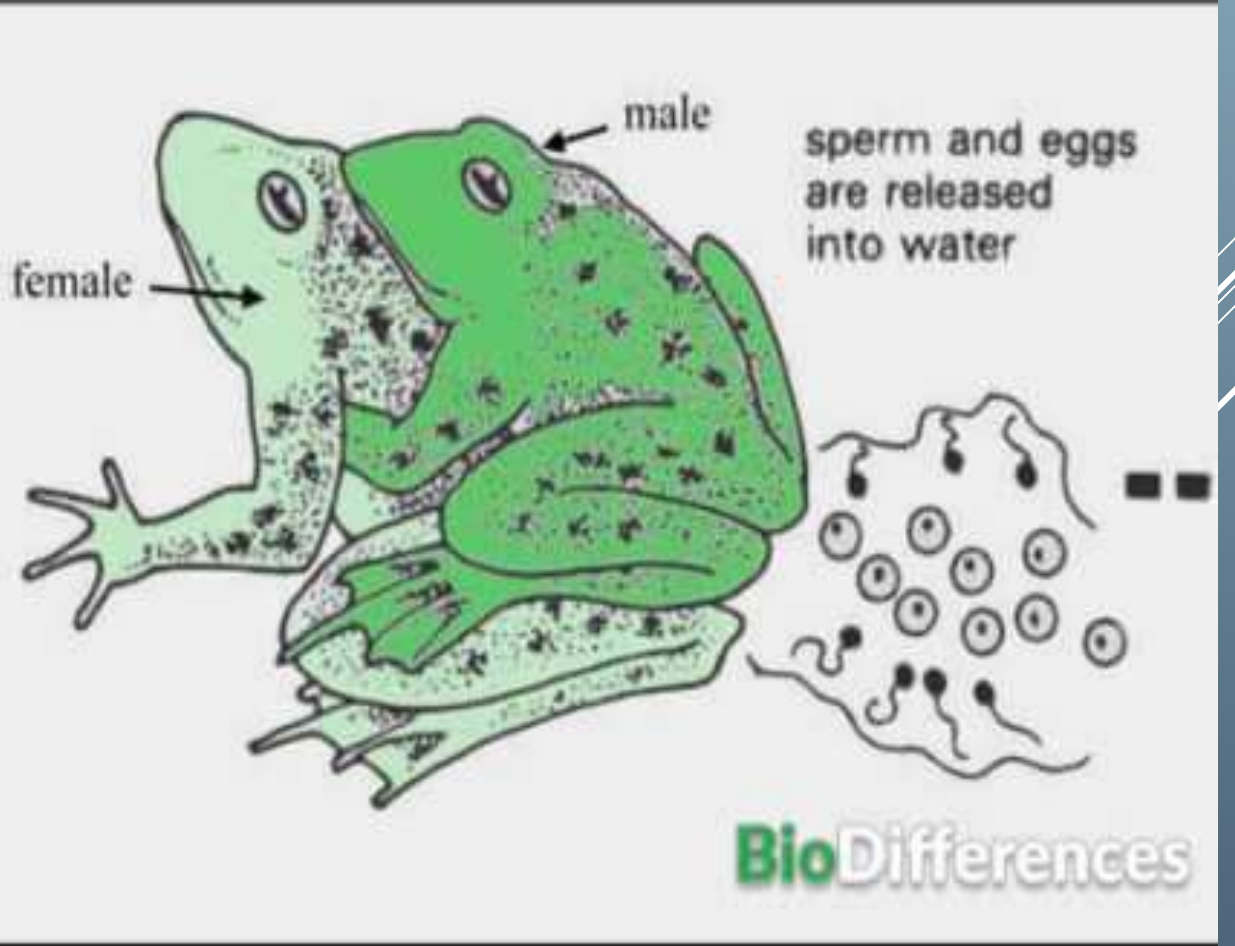
- When the fusion of sperm and egg takes place outside the female parent, it is called external fertilization. Only a minority of organisms exhibit this type of gamete fusion. For example, fish, frogs, etc. Here the female parent deposits her eggs in the external environment and later, the male parent ejects his sperm over them, and then the fusion of the gametes takes place in the external environment.
- Gametes that fuse externally have to face many challenges. Since eggs and sperms are deposited in the external environment, the chances of fusion are very less. Predators may eat the eggs or the zygote that is formed. To compensate for this loss, organisms like fish and frogs lay hundreds of eggs at a time.

Internal Fertilization

VS

External Fertilization



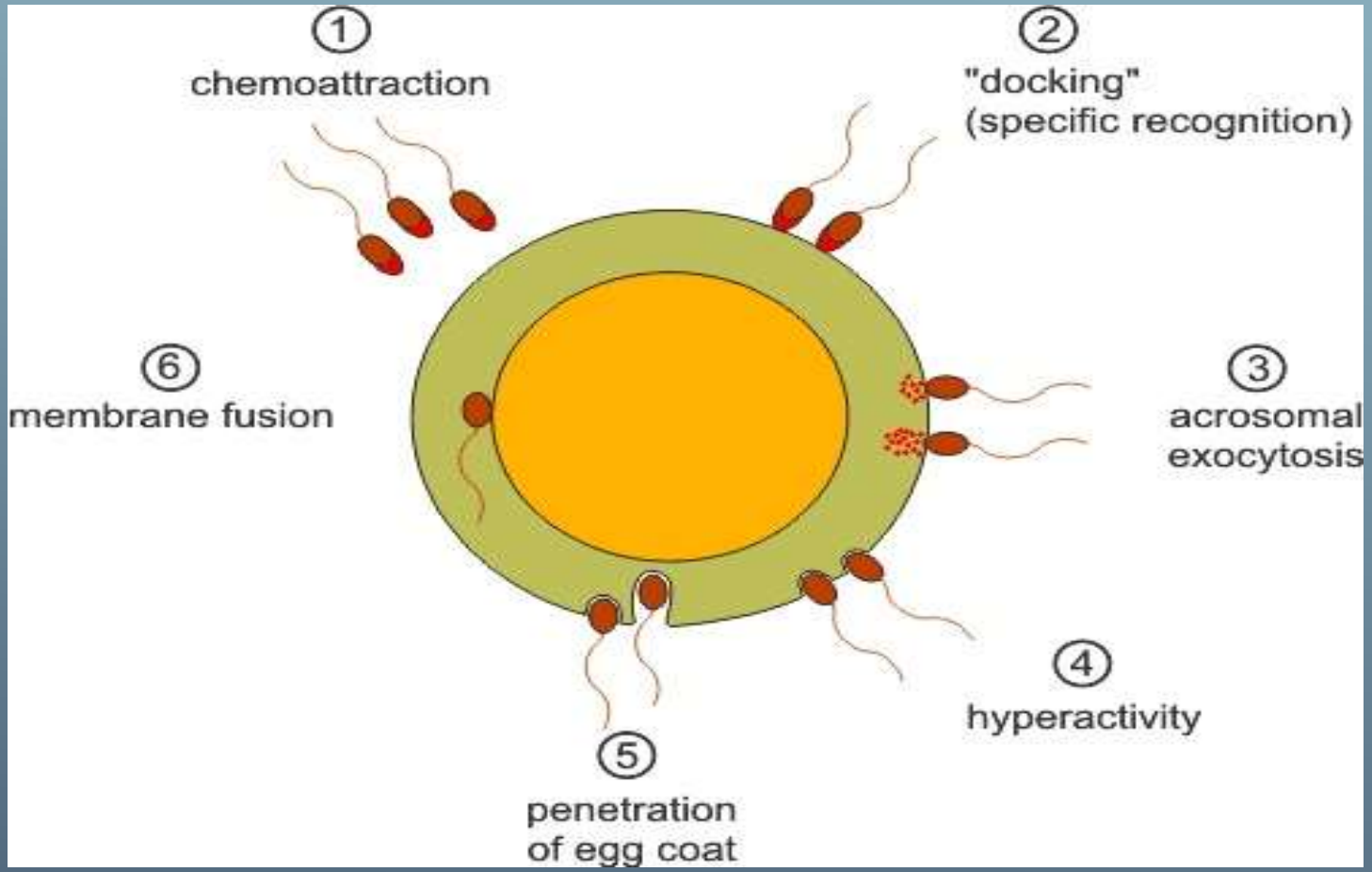


- External fertilization usually occurs in aquatic environments where both eggs and sperm are released into the water.
- After the sperm reaches the egg, fertilization takes place.
- Most external fertilization happens during the process of spawning where one or several females release their eggs and the male(s) release sperm in the same area, at the same time.
- The release of the reproductive material may be triggered by water temperature or the length of daylight.
- Nearly all fish spawn, as do crustaceans (such as crabs and shrimp), mollusks (such as oysters), squid, and echinoderms (such as sea urchins and sea cucumbers).

EXTERNAL FERTILIZATION

- Internal Fertilization
- Internal fertilization occurs most often in land-based animals, although some aquatic animals also use this method. There are three ways that offspring are produced following internal fertilization. In **oviparity**, fertilized eggs are laid outside the female's body and develop there, receiving nourishment from the yolk that is a part of the egg. This occurs in most bony fish, many reptiles, some cartilaginous fish, most amphibians, two mammals, and all birds. Reptiles and insects produce leathery eggs, while birds and turtles produce eggs with high concentrations of calcium carbonate in the shell, making them hard. Chicken eggs are an example of this second type.
- In **ovoviparity**, fertilized eggs are retained in the female, but the embryo obtains its nourishment from the egg's yolk and the young are fully developed when they are hatched. This occurs in some bony fish (like the guppy *Lebistes reticulatus*), some sharks, some lizards, some snakes (such as the garter snake *Thamnophis sirtalis*), some vipers, and some invertebrate animals (like the Madagascar hissing cockroach *Gromphadorhina portentosa*).
- In **viviparity** the young develop within the female, receiving nourishment from the mother's blood through a placenta. The offspring develops in the female and is born alive. This occurs in most mammals, some cartilaginous fish, and a few reptiles.

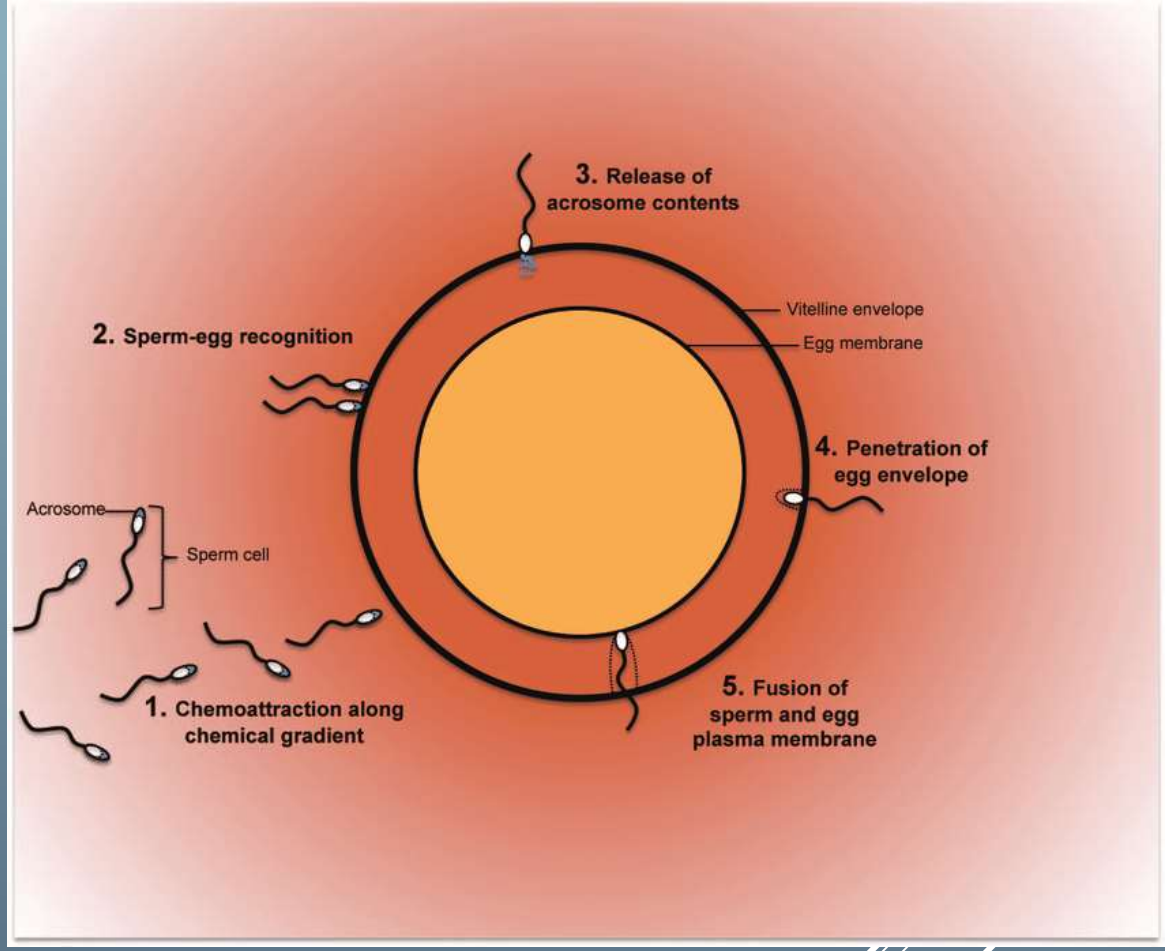
- Internal fertilization has the advantage of protecting the fertilized egg from dehydration on land.
- The embryo is isolated within the female, which limits predation on the young.
- Internal fertilization enhances the fertilization of eggs by a specific male.
- Fewer offspring are produced through this method, but their survival rate is higher than that for external fertilization.


1
chemoattraction
2
"docking"
(specific recognition)
6
membrane fusion
3
acrosomal
exocytosis
4
hyperactivity
5
penetration
of egg coat

CHEMOTAXIS

- Activation of sperm swimming movements requires stimulation of the propulsion machinery of the sperm.
- Sperm are activated in a series of steps.
- First, contact with diffusible molecules contained in **egg jelly** initiates **chemotaxis**.
- Chemotaxis is the process by which a migrating (or swimming) cell moves toward a higher concentration of a diffusible or substrate-bound guidance molecule.
- Second, physical contact with egg jelly occurs.
- This causes the **acrosome reaction**, which is triggered a rise in internal **calcium concentration** inside the sperm head.

- Chemotaxis –
- Sperm cells of many species are guided to the egg by chemoattractants, a process called chemotaxis.
- Motor proteins in the flagellum of the sperm generate a regular beat of the flagellum, which propels the sperm in a fluid.
- In the absence of a chemoattractant, sperm swim in circles in two dimensions and along helical paths in three dimensions.
- Chemoattractants stimulate a signaling system in the flagellum, which regulates the motors to control sperm swimming.



- In the presence of a chemoattractant, swimming paths are drifting circles in two dimensions and deformed helices in three dimensions.
- The swimming paths can be described by a dynamical system that exhibits different dynamic regimes, which correspond to different chemotactic behaviours.
- **Sperm chemotaxis plays an important role for fertilization. It implies that a swimming sperm cell steers upwards a gradient of a chemoattractant that is released by the egg.**

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- A picomolar concentration gradient of Progesterone (P), the main steroidal component secreted by the cumulus cells that surround the egg, attracts human spermatozoa.
- Calcium signaling plays a key role in sperm physiology

- Chemotaxis is mediated by a signaling system that is located in the sperm flagellum.
- Specific receptors in the flagellar membrane are activated upon binding of chemoattractant molecules and start the production of cyclic guanine monophosphate (cGMP).
- A rise in cGMP gates the opening of potassium channels and causes a hyperpolarization of the flagellar membrane.
- This hyperpolarization triggers the opening of voltage-gated calcium channels and the membrane depolarizes again.
- The overall effect of this signaling cascade is the generation of a transient increase of the internal calcium concentration along the flagellar length.
- This calcium signal is thought to regulate the activity of dynein motor proteins in the flagellum, thus affecting the geometry of the swimming path.
- Interestingly, this signaling system operates over a vast range of chemoattractant concentrations ranging from picomolar to micromolar concentrations

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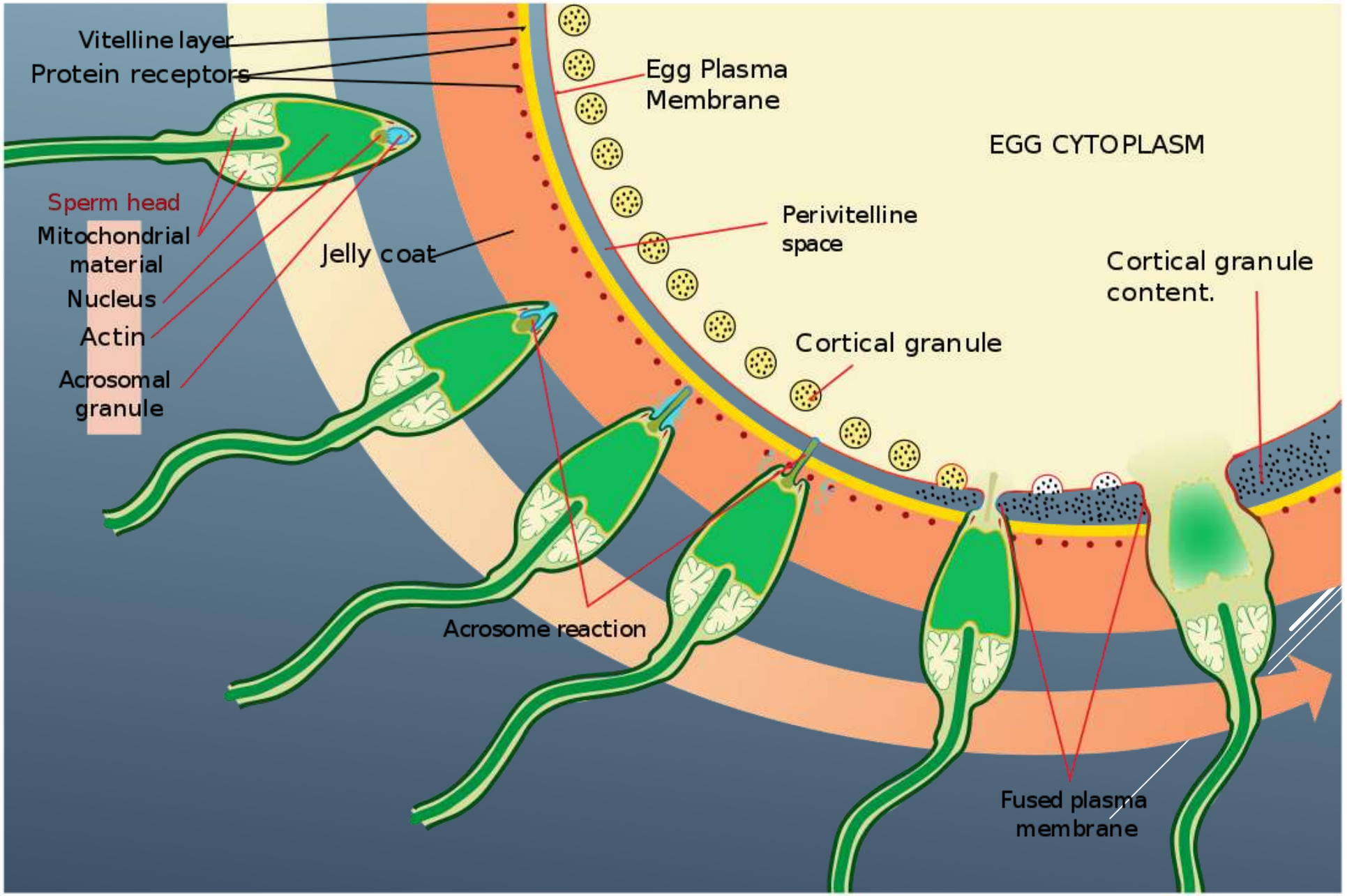
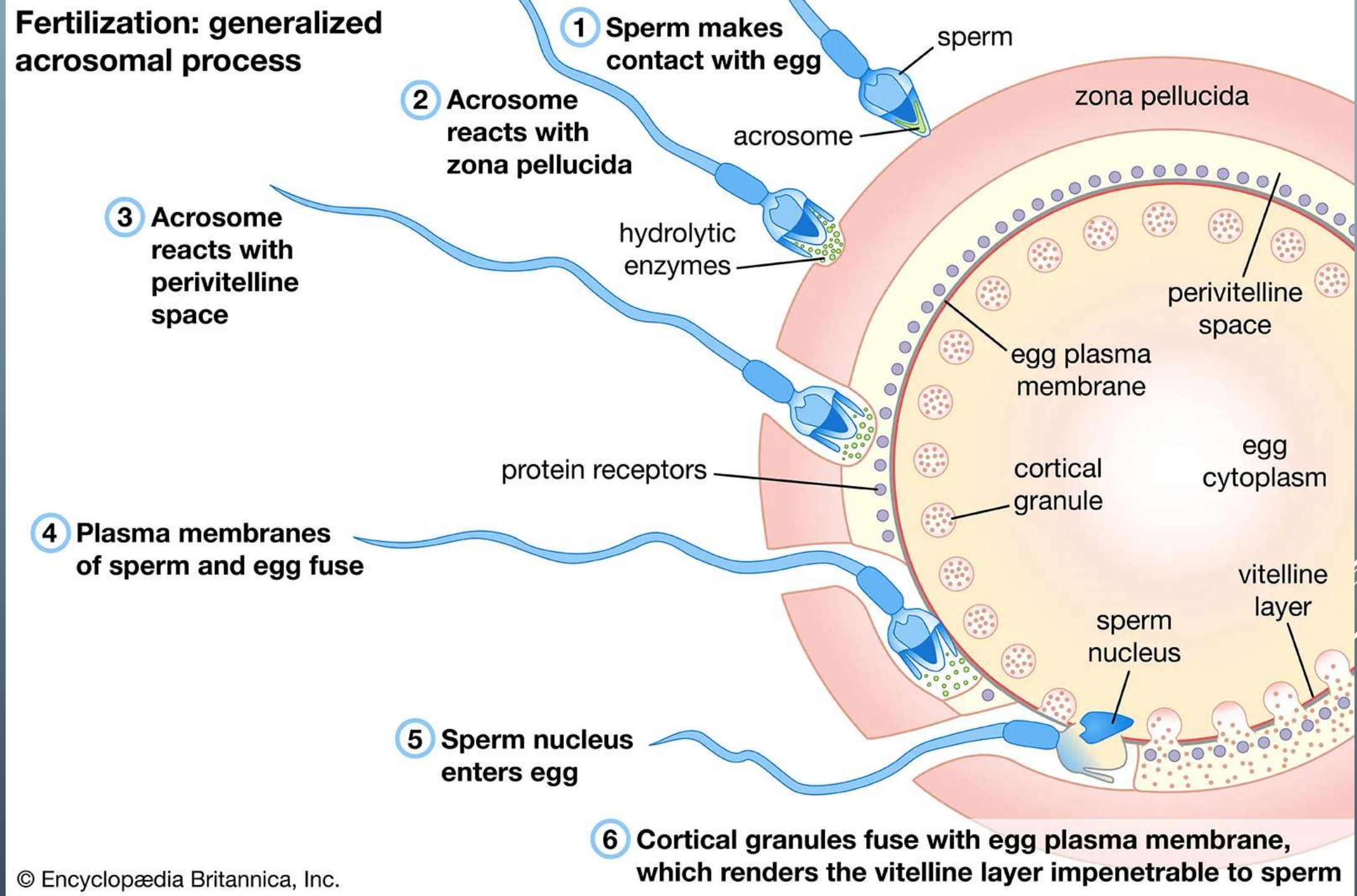

Vitelline layer
Protein receptors
Egg Plasma Membrane
EGG CYTOPLASM
Sperm head
Mitochondrial material
Nucleus
Actin
Acrosomal granule
Jelly coat
Perivitelline space
Cortical granule content.
Cortical granule
Acrosome reaction
Fused plasma membrane


Fertilization: generalized acrosomal process
1 Sperm makes contact with egg
2 Acrosome reacts with zona pellucida
3 Acrosome reacts with perivitelline space
4 Plasma membranes of sperm and egg fuse
5 Sperm nucleus enters egg
6 Cortical granules fuse with egg plasma membrane, which renders the vitelline layer impenetrable to sperm
sperm
acrosome
zona pellucida
hydrolytic enzymes
perivitelline space
egg plasma membrane
protein receptors
cortical granule
egg cytoplasm
vitelline layer
sperm nucleus
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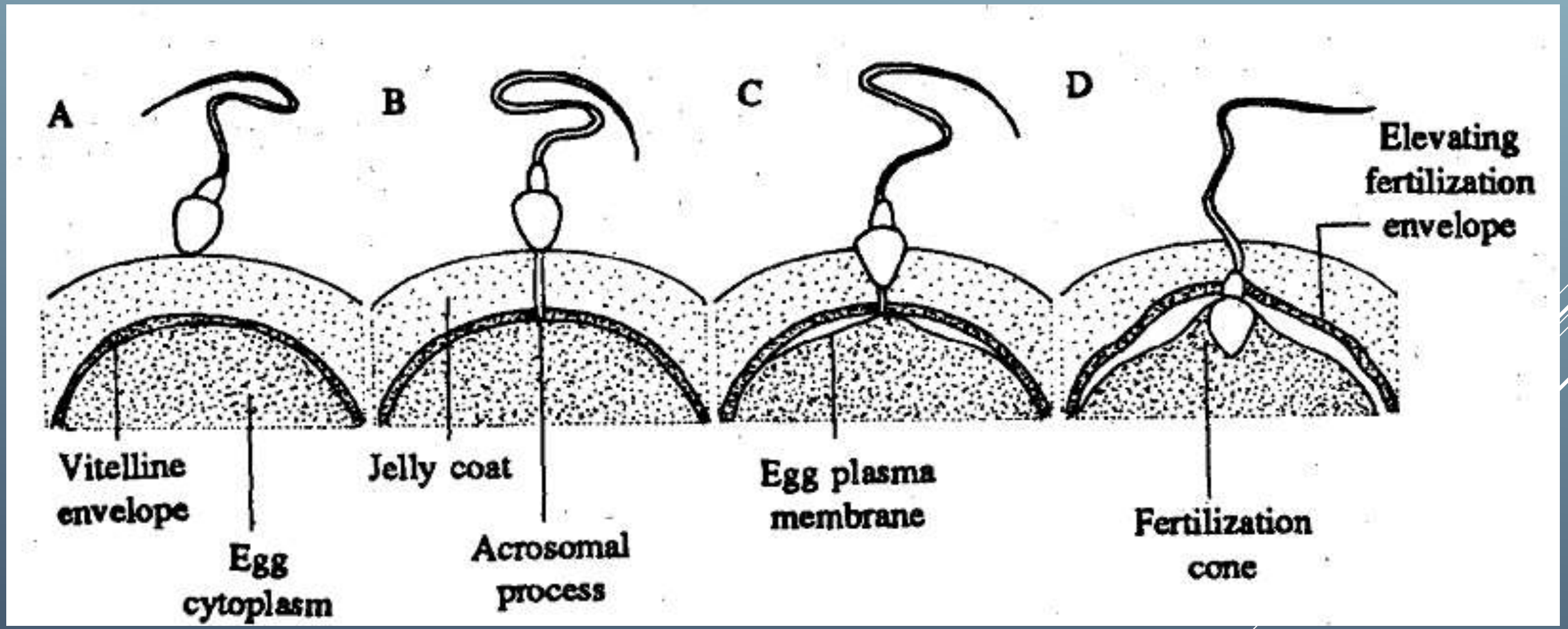

A
B
C
D
Elevating fertilization envelope
Vitelline envelope
Egg cytoplasm
Jelly coat
Acrosomal process
Egg plasma membrane
Fertilization cone

PREVENTION OF POLYSPERMY

- The entrance of multiple sperm—**polyspermy**—leads to disastrous consequences in most organisms.
- The most common way is to prevent the entry of more than one sperm into the egg.
- The sea urchin egg has two mechanisms to avoid polyspermy: a fast reaction, accomplished by an electric change in the egg plasma membrane, and a slower reaction, caused by the exocytosis of the cortical granules

THE FAST BLOCK TO POLYSPERMY

- The **fast block to poly-spermy** is achieved by changing the electric potential of the egg plasma membrane.
- This membrane provides a selective barrier between the egg cytoplasm and the outside environment, and the ionic concentration of the egg differs greatly from that of its surroundings.
- This concentration difference is especially significant for sodium and potassium ions.
- Seawater has a particularly high sodium ion concentration, whereas the egg cytoplasm contains relatively little sodium.
- The reverse is the case with potassium ions.
- This condition is maintained by the plasma membrane, which steadfastly inhibits the entry of sodium ions into the oocyte and prevents potassium ions from leaking out into the environment.

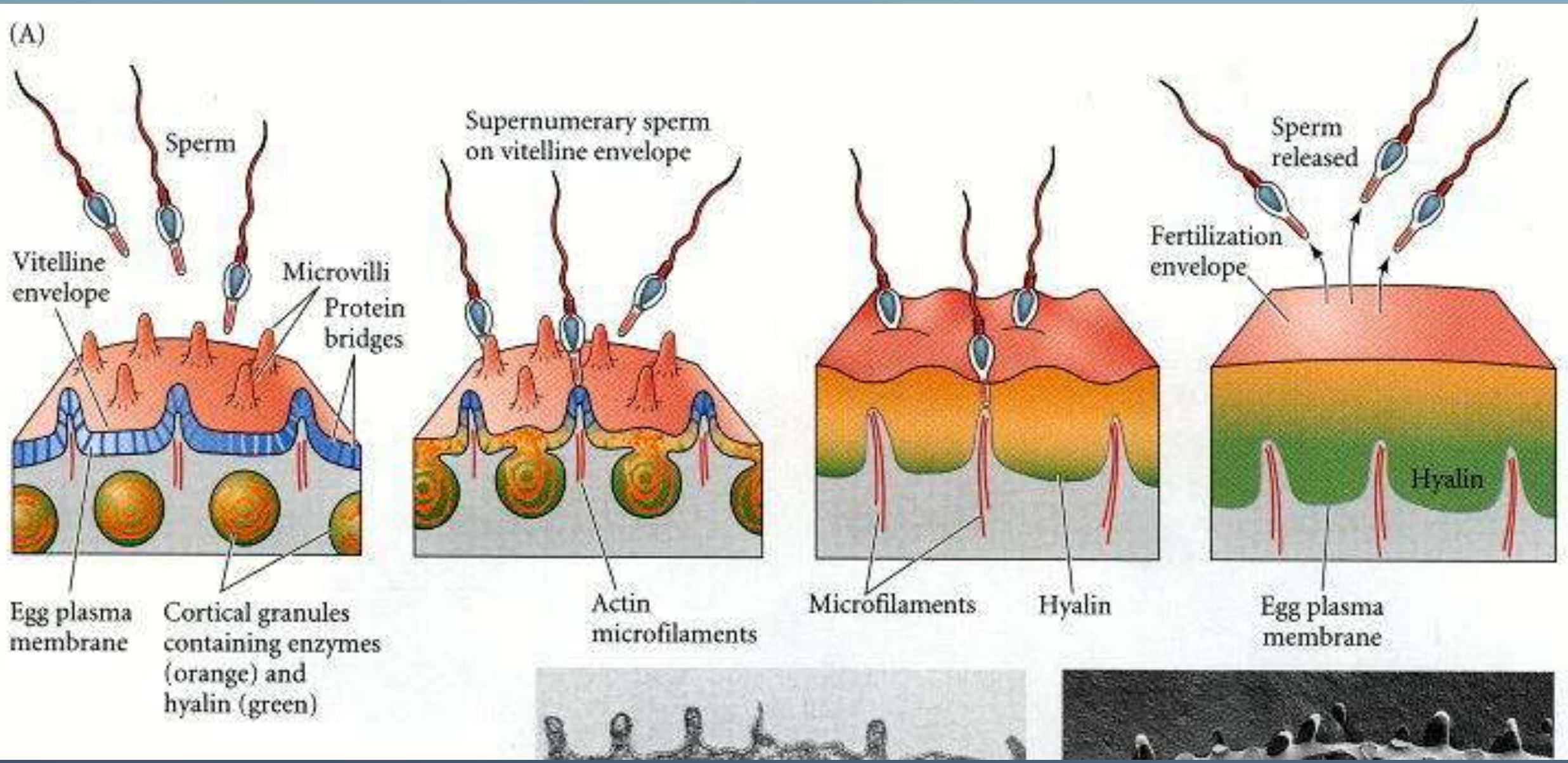
- If we insert an electrode into an egg and place a second electrode outside it, we can measure the constant difference in charge across the egg plasma membrane.
- This **resting membrane potential** is generally about 70 mV, usually expressed as –70 mV because the inside of the cell is negatively charged with respect to the exterior.

- Within 1–3 seconds after the binding of the first sperm, the membrane potential shifts to a positive level, about +20 mV (Longo et al. 1986).
- This change is caused by a small influx of sodium ions into the egg (Figure 7.22A).
- Although sperm can fuse with membranes having a resting potential of –70 mV, they cannot fuse with membranes having a positive resting potential, so no more sperm can fuse to the egg.
- It is not known whether the increased sodium permeability is due to the *binding* of the first sperm or to the *fusion* of the first sperm with the egg

THE SLOW BLOCK TO POLYSPERMY

- The eggs of sea urchins (and many other animals) have a second mechanism to ensure that multiple sperm do not enter the egg cytoplasm (Just 1919).
- The fast block to polyspermy is transient, since the membrane potential of the sea urchin egg remains positive for only about a minute.
- This brief potential shift is not sufficient to prevent polyspermy, which can still occur if the sperm bound to the vitelline envelope are not somehow removed (Carroll and Epel 1975).
- This removal is accomplished by the cortical granule reaction, a slower, mechanical block to polyspermy that becomes active about a minute after the first successful sperm-egg attachment.

- Directly beneath the sea urchin egg plasma membrane are about 15,000 cortical granules, each about 1 μm in diameter.
- Upon sperm entry, these cortical granules fuse with the egg plasma membrane and release their contents into the space between the plasma membrane and the fibrous mat of vitelline envelope proteins.
- Several proteins are released by this cortical granule exocytosis. The first are proteases.
- These enzymes dissolve the protein posts that connect the vitelline envelope proteins to the cell membrane, and they clip off the bindin receptor and any sperm attached to it.
- Mucopolysaccharides released by the cortical granules produce an osmotic gradient that causes water to rush into the space between the plasma membrane and the vitelline envelope, causing the envelope to expand and become the **fertilization envelope** .
- A third protein released by the cortical granules, a peroxidase enzyme, hardens the fertilization envelope by crosslinking tyrosine residues on adjacent proteins.
- the fertilization envelope starts to form at the site of sperm entry and continues its expansion around the egg. As it forms, bound sperm are released from the envelope.
- This process starts about 20 seconds after sperm attachment and is complete by the end of the first minute of fertilization.
- Finally, a fourth cortical granule protein, hyalin, forms a coating around the egg.
- The egg extends elongated microvilli whose tips attach to this **hyaline layer**.
- This layer provides support for the blastomeres during cleavage.


(A)
Sperm
Vitelline envelope
Microvilli
Protein bridges
Egg plasma membrane
Cortical granules containing enzymes (orange) and hyalin (green)
Supernumerary sperm on vitelline envelope
Actin microfilaments
Microfilaments
Hyalin
Sperm released
Fertilization envelope
Hyalin
Egg plasma membrane

Thank You