

Lecture 3

Reproductive biology and Embryology

Gametes

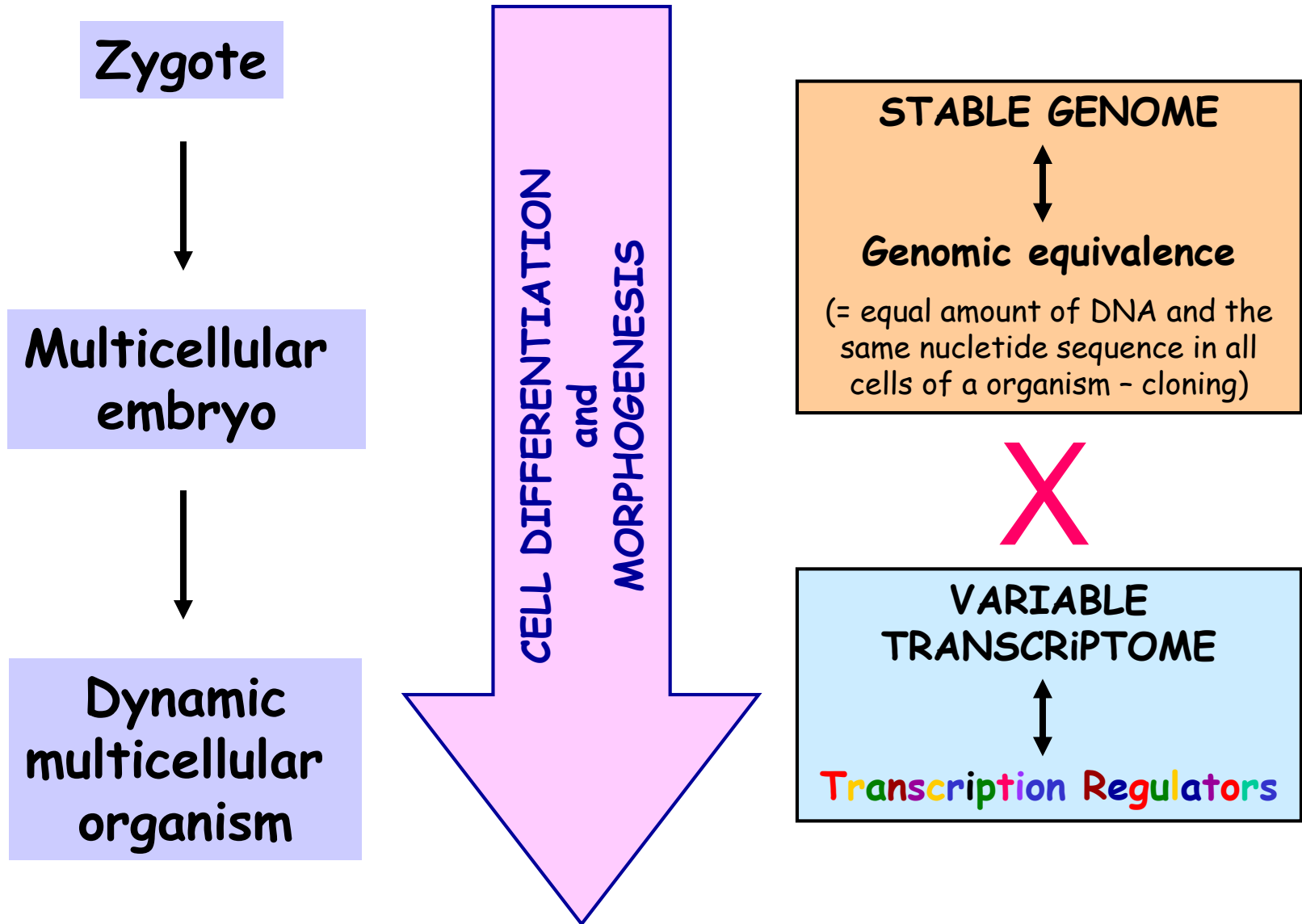
- Meiosis
- Structure and development
- Differences between oogenesis and spermatogenesis
- Regulation of gametogenesis
- Ovarian and menstrual cycles
- Ovulation
- Transport of gametes, sperm capacitation, acrosome reaction

Fertilization and Early Embryogenesis

- Cortical reaction
- Cleavage, morula, blastocyst
- Activation of embryonal genome
- Embryonic stem cells, nuclear transfer (cloning)

Brno, March 2020

Embryology: what does it cover?

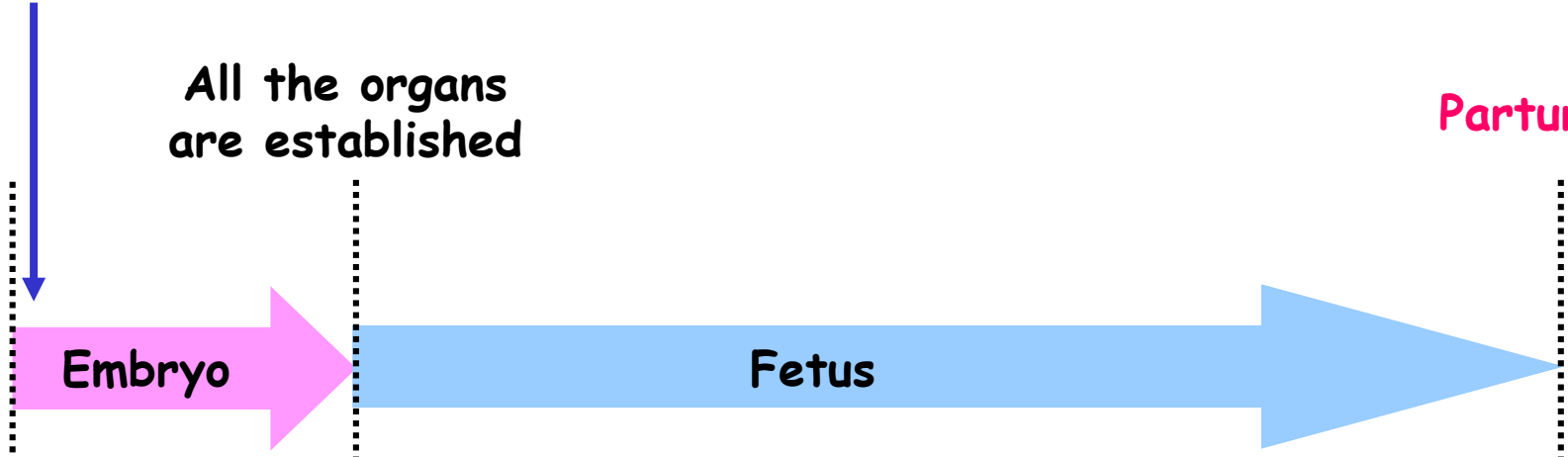


Embryonal x Fetal Development

Early embryo
before implantation

All the organs
are established

Parturition



Fertilization

Week 8

Week
39-40

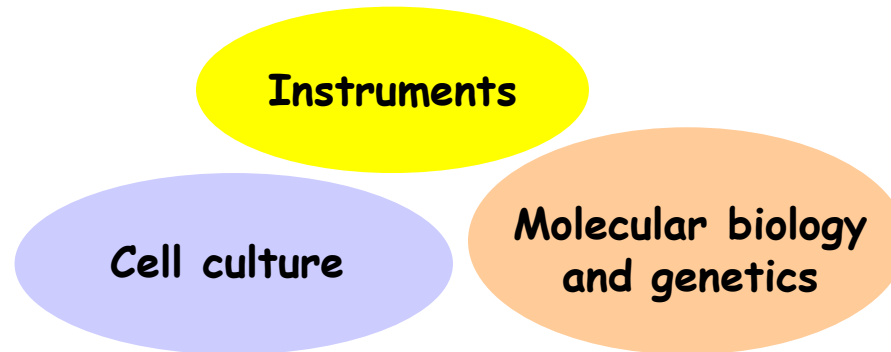
The primitive heart starts beating at 4 weeks.



7 weeks



Any use of understanding principles of reproduction and embryonal/fetal development?



- **Infertility treatments**
- **Contraception**
- **Avoidance of developmental abnormalities**
 - Genetic basis of gamete development
 - Examination of genetic status (amniotic fluid)
 - Understanding the effects of teratogenic compounds
 - Intrauterine examination - sonography
 - Intrauterine surgeries
 - Others to come

Reproduction

- allows for continuity of a given species via propagation of its individuals
- key element in reproduction is the transfer of DNA duplicate from parents onto progeny

Individuals of **different sex** produce **different gametes**



Key element in **sexual reproduction**

Sexual reproduction mediated by gametes

may seem to be too complicated and much less effective than asexual but

serves very significant adaptation role.

This adaptation role realizes via unique genetic processes, which take place during development of gametes - eggs and sperm.

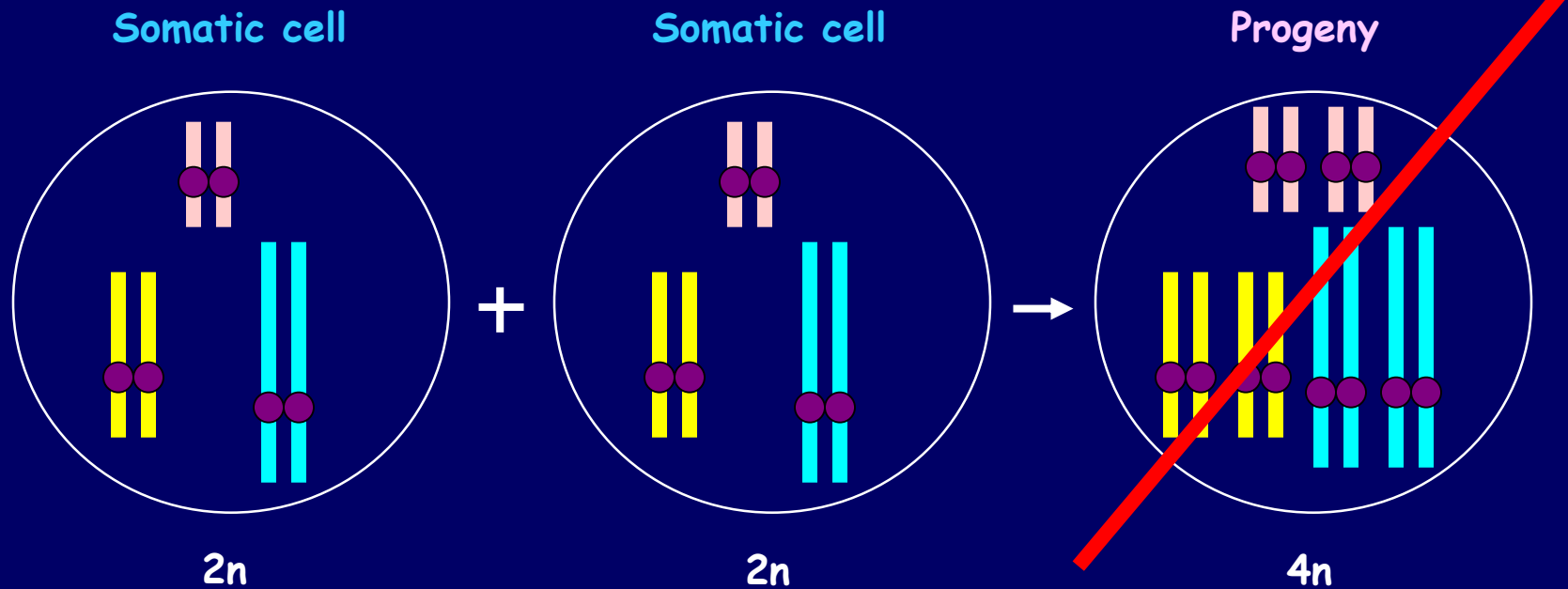
Although development of eggs and sperm differ in many morphogenetic details, key genetic processes taking place in both types of gametes are principally the same.

Genetic processes that are crucial for gametogenesis take place during meiotic cell division - MEIOSIS

These genetic processes include:

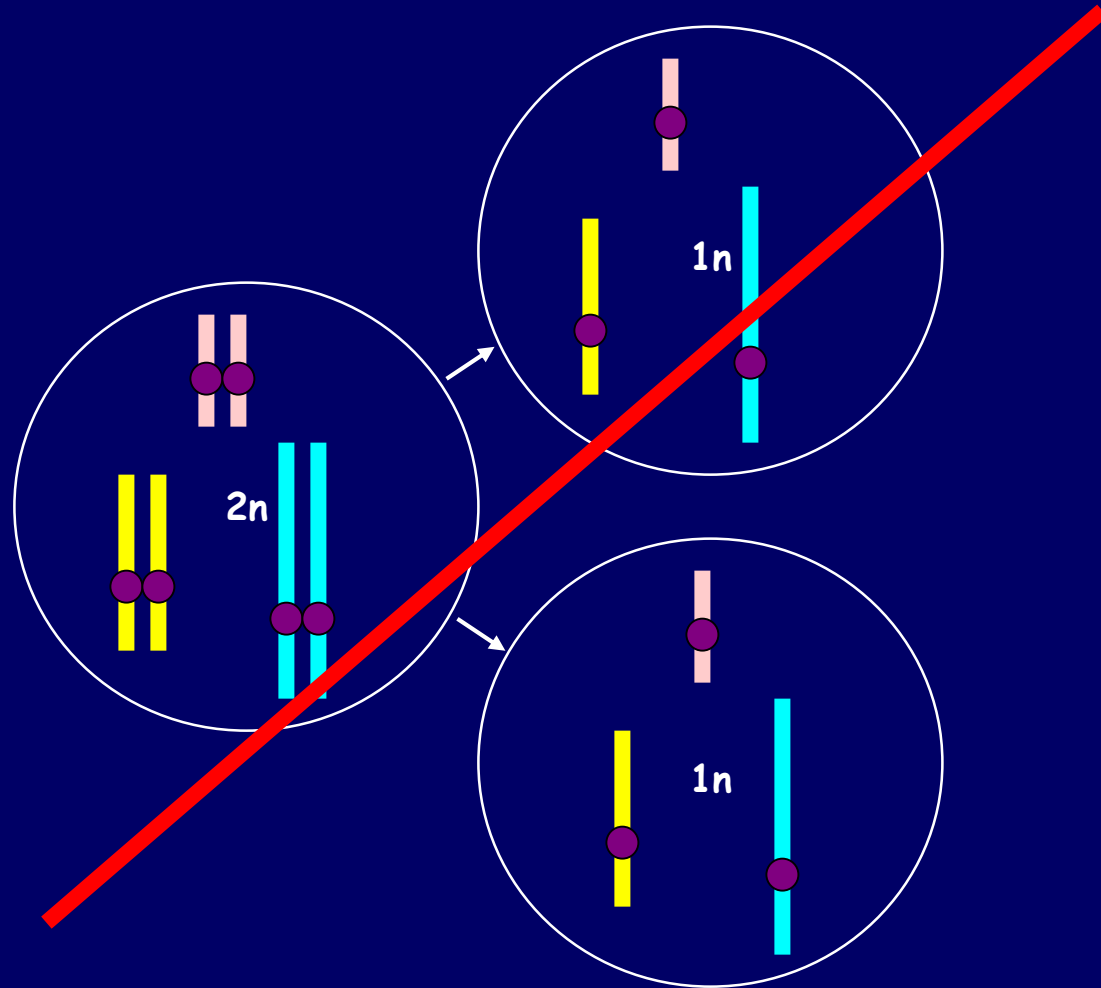
- „Crossing over“
- Independent segregation chromosomes
- Reduction of the number of chromosomes

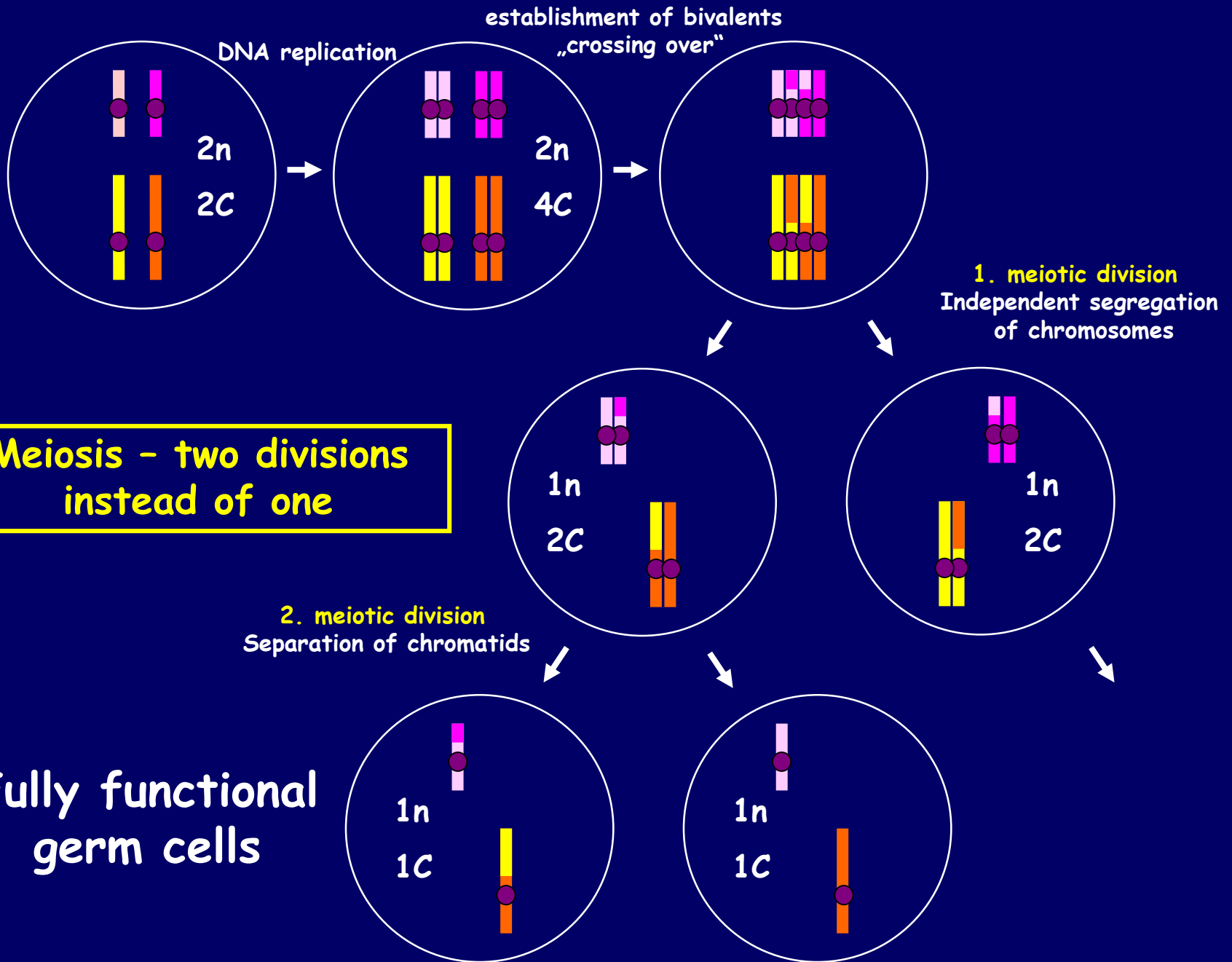
Reduction of the number of chromosomes Why?



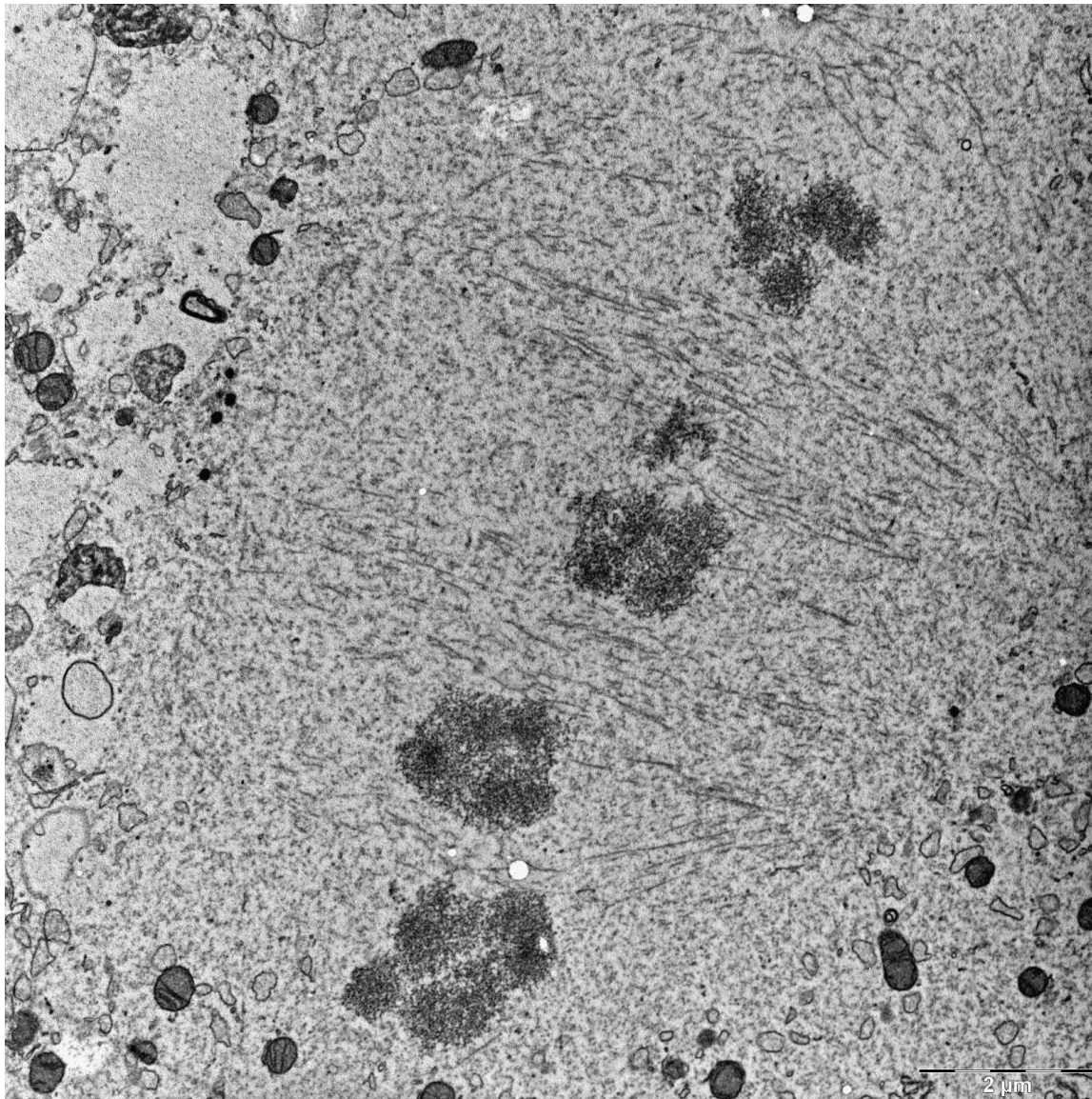
Gametes have to contain haploid number of chromosomes (n) in order to prevent multiplication of chromosomes in progeny above a diploid number ($2n$)

In principle, the number of chromosomes could be reduced in one step by just separating homologous chromosomes without preceding replication of DNA (DNA synthesis)





MI oocyte - tetrads



- „Crossing over“
- Independent segregation of chromosomes
- Fertilization

are sources of genetical diversity, that underlies adaptation of living organisms.

S
A
M
E

Genetic function

♂ Sperm

×

♀ Eggs

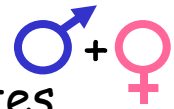
Significance for
embryogenesis
(reproduction)

Morphological
and physiological
properties

Development and
underlying regulatory
mechanisms


D
I
F
F
E
R
E
N
T


Primordial germ cells - PGC



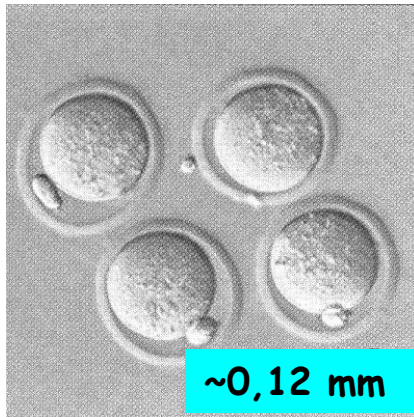
- stem cells, which are common to both sperm cells and oocytes
- originate in yolk sac (extraembryonally)
- divide mitotically while migrating into gonad anlagen (genital ridges) (due to signals from surrounding environment - laminin, kit-ligand, TGF-beta1, ...)
- in man PGCs are sexually indifferent until the 6th week of embryonic development

DEVELOPMENTAL PROCESSES

- after reaching puberty, sperm cells are produced in testes continuously until high age (two testes of man produce about 1000 spermatozoa every second) 

- numbers of oocytes (follicles) in ovary is given at the time of birth and do not increase (in woman ~500 000) 
- only small number of oocytes develop into fertilizable eggs (in woman ~400)
- at the time of menopause, ovary contains only small number of remaining oocytes (in woman ~100-1000)

Oocyte



One of the biggest and most „precious“
(by both number and significance) cells.

Paradoxical cell

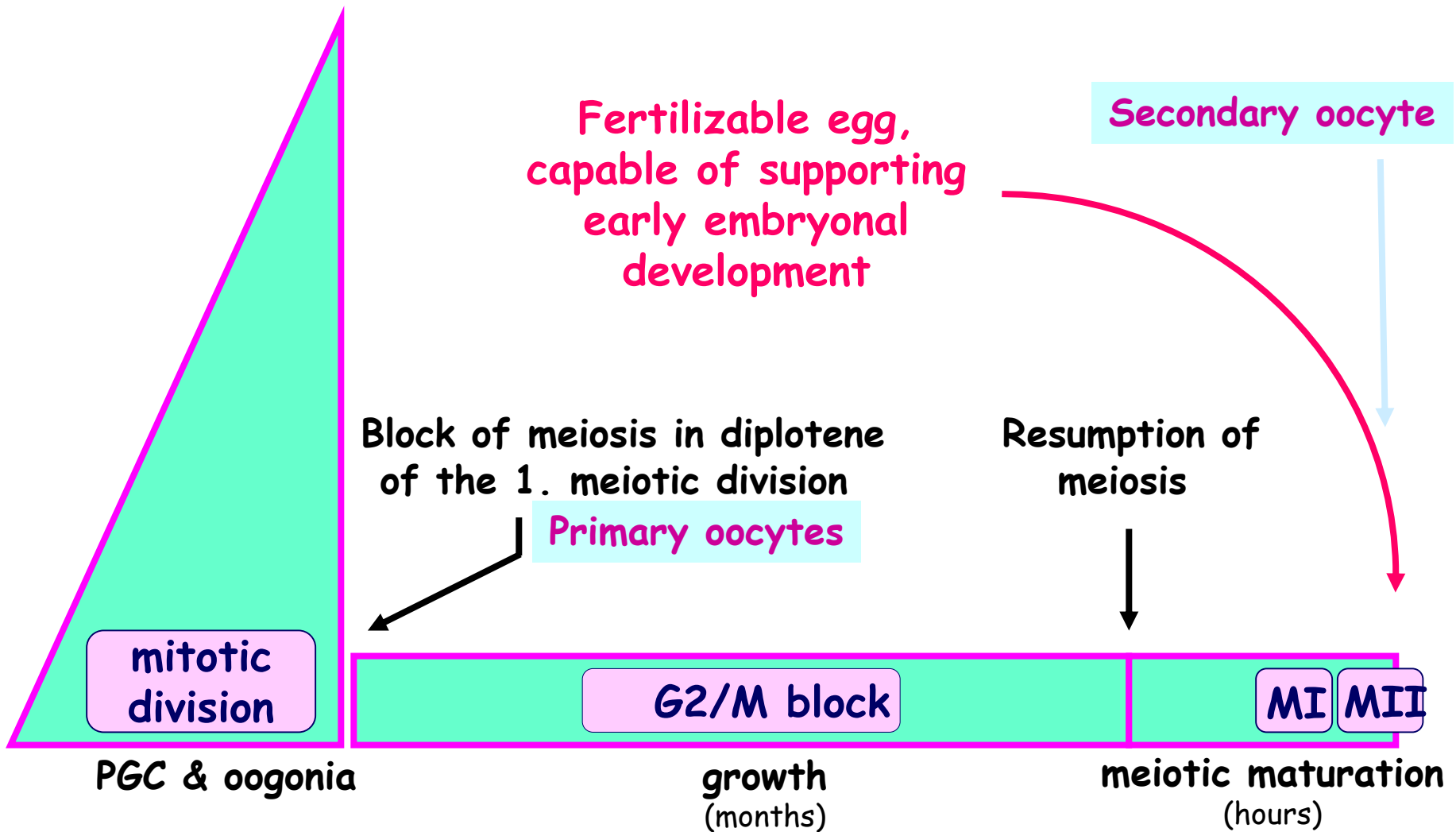
Highly specialized cell.
The only cell in the female body that can undergo meiosis and fertilization, and thus give rise to a new individual.

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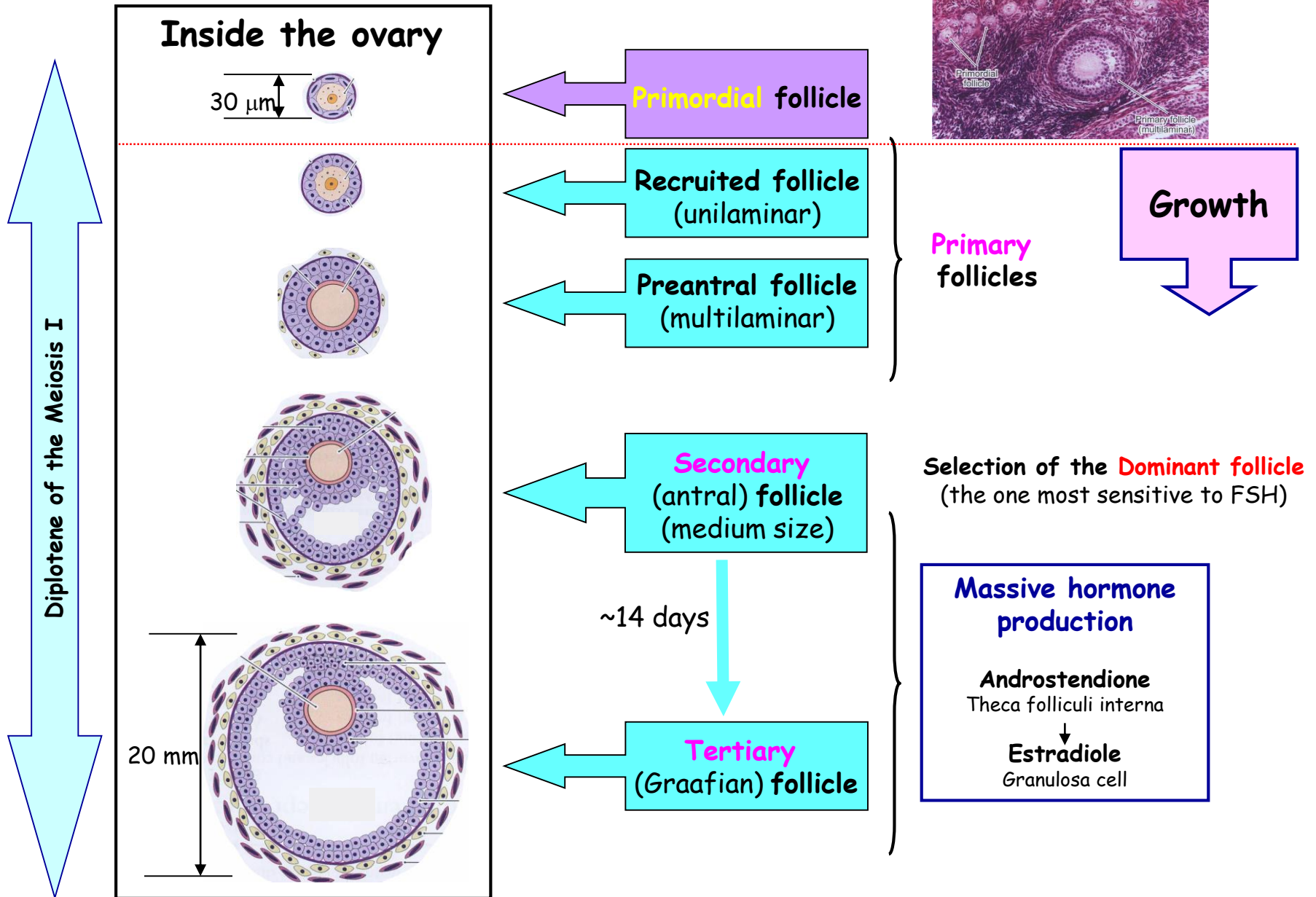
„Totipotent“ cell
It can generate all the cellular diversity that is typical for multicellular organism.

Even the era of cloning did not replace the functions of egg !

Key periods of oocyte development



Where and how the oocyte development is achieved ? (1)



Where and how the oocyte development is achieved ? (2)

Oocyte growth

Takes place in **ovary** (along with the growth of follicle)

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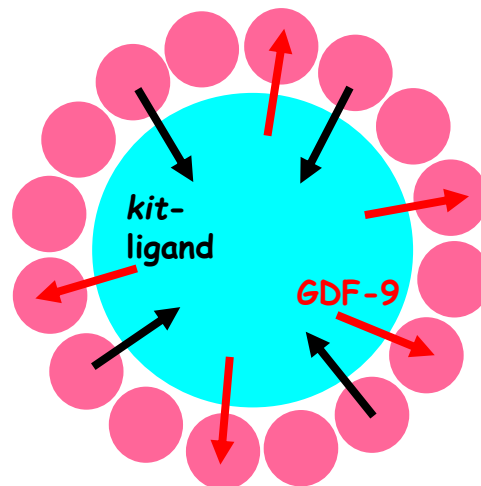
Signal that initiates growth is **not known**
(it is not FSH - hypophysectomy does not prevent growth)

&

It is fully dependent on the **contact of oocyte with granulosa cells** of the follicle (mediated for example by the gap junction protein connexin-37)

&

Communication between oocyte and granulosa cells is **bidirectional**



Where and how the oocyte development is achieved ? (3)

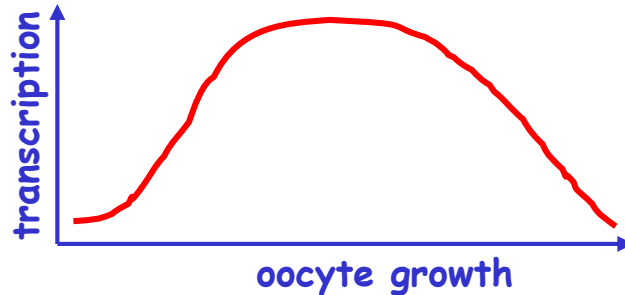
Oocyte growth

Slow process (several months in woman)

100x increase in volume - **accumulation of organelles a molecules** providing egg with the ability to support early embryogenesis until reaching autonomy (about 10^5 mitochondria accumulated in oocyte supports embryogenesis until blastocyst stage)

Intensive transcription - accumulation of mRNA in dormant state (regulated by polyadenylation and ?)

Fully grown oocyte - ~2,5 ng total mRNA



Transkriptome
and proteome -
underlie unique
properties of
oocyte

Intensive translation - many proteins (very limited knowledge)

Example: ZP1, ZP2, ZP3 - proteins of zona pellucida

Fully grown oocyte - ~120 ng total protein

Where and how the oocyte development is achieved ? (4)

Epigenetic changes occurring during oocyte growth

Reactivation of X chromosome

- **somatic cells** - one X chromosome is inactivated by hypermethylation of cytosine residues in molecule of DNA
- **growing oocyte** - both X chromosomes are active (crucial for oocyte development - karyotype 45, XO results in an abnormal development of ovaries)

&

Genomic imprinting

- epigenetic modification of autosomal chromosomes that leads to monoallelic expression of genes - due to activity of enzyme DNA methyltransferase
- PGCs are globally demethylated
- imprinting is newly established during oocyte growth (about 70-80 genes)

Abnormalities in imprinting may result in spontaneous abortions in assisted reproduction !!!
(*in vitro* manipulation with gametes and embryos may produce abnormalities in imprinting)

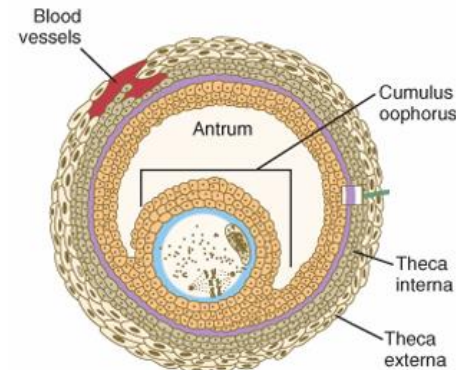
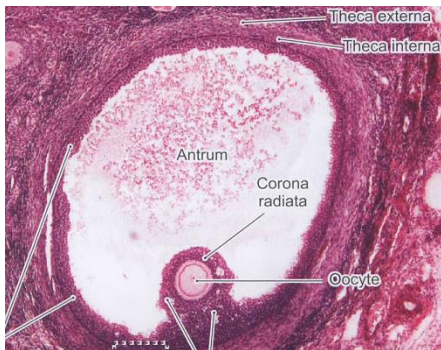
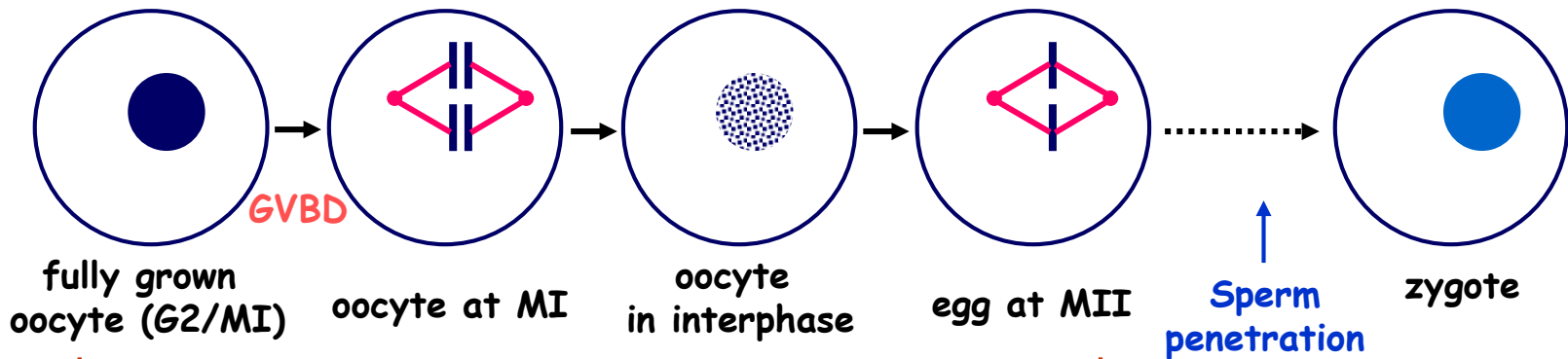
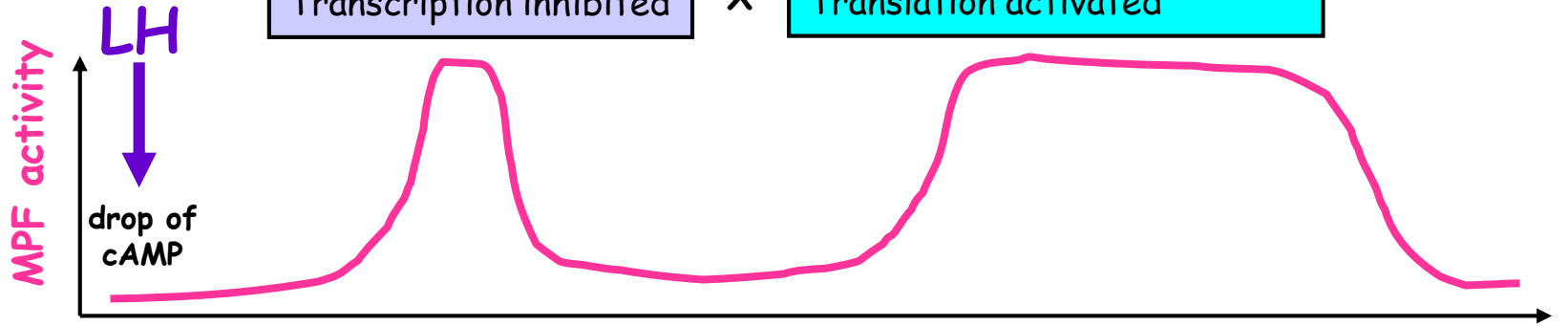
Where and how the oocyte development is achieved ? (5)

The last hours before ovulation - meiotic maturation

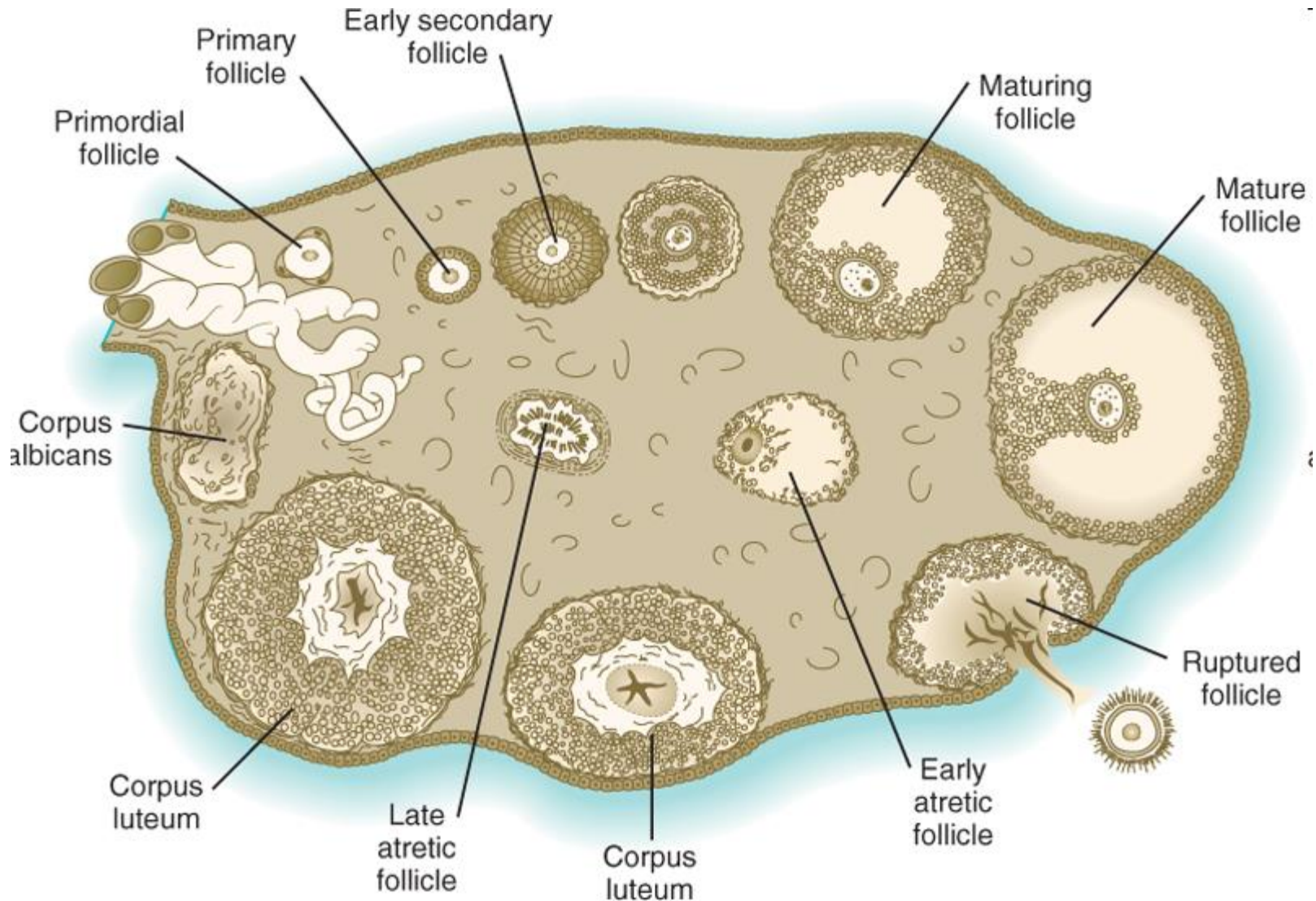
Transcription inhibited

X

Translation activated

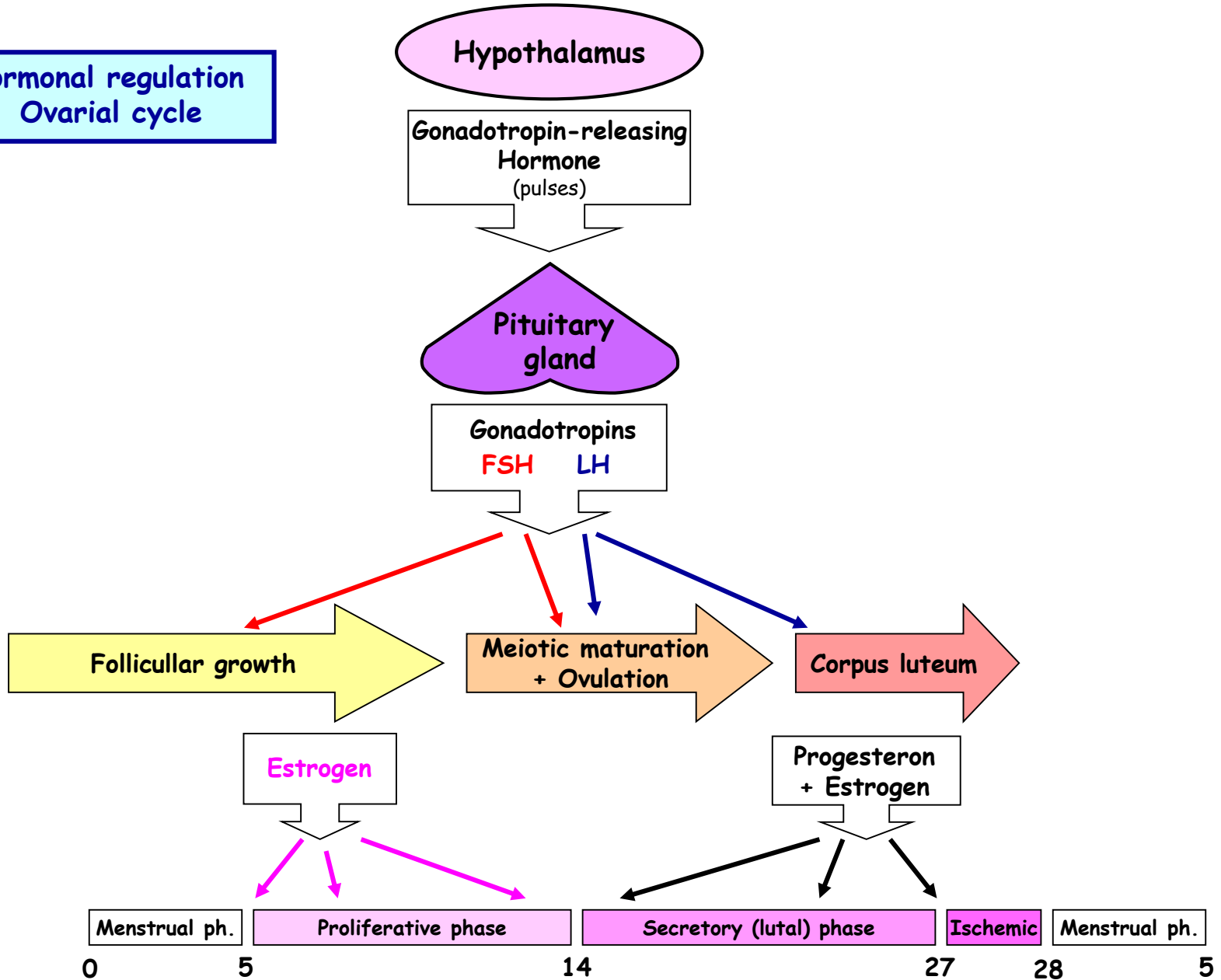


The final look into the ovary

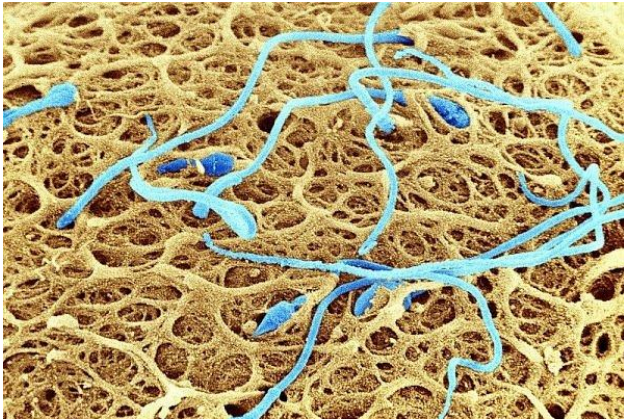


Where and how the oocyte development is achieved ? (6)

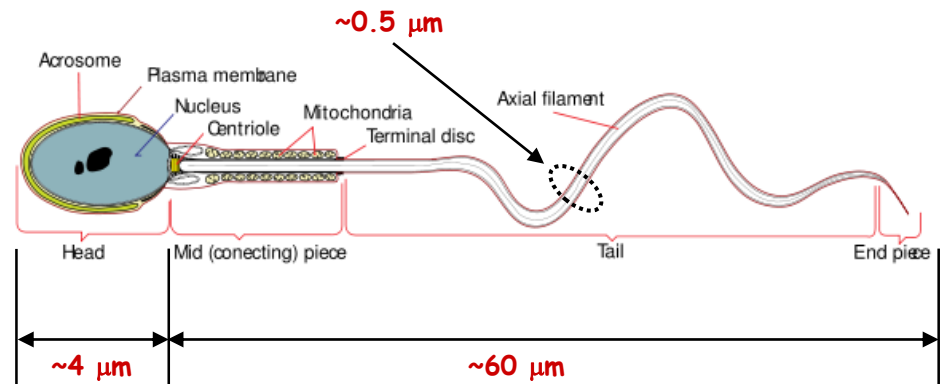
Hormonal regulation
Ovarial cycle



Sperm cell development - Spermatogenesis (1)



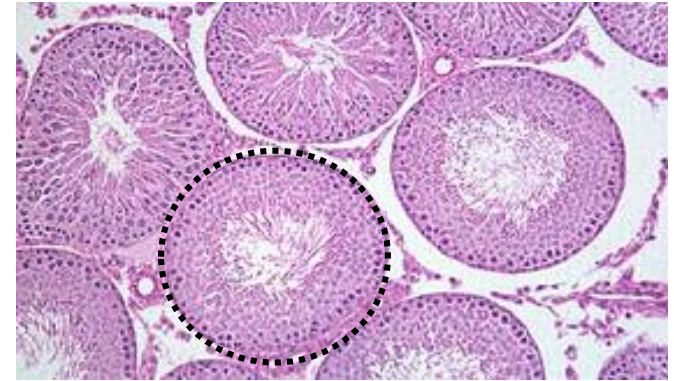
Sperms on the oocyte



Minimal ejaculate (WHO)

- Volume - 1.5 ml
- Sperm number - 15.1 millions/ml
- Motility - 40%

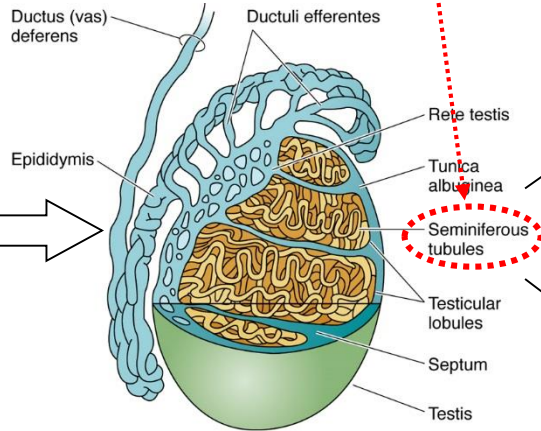
Sperm cell development (2)



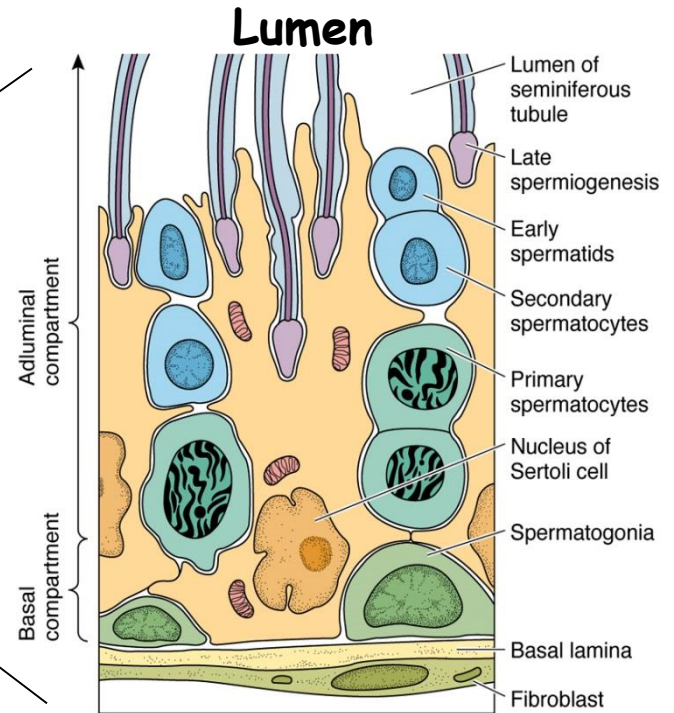
Before puberty

Slowly mitotically dividing spermatogonia in seminiferous tubuli

After puberty



~0.25 mm
~0.5 km

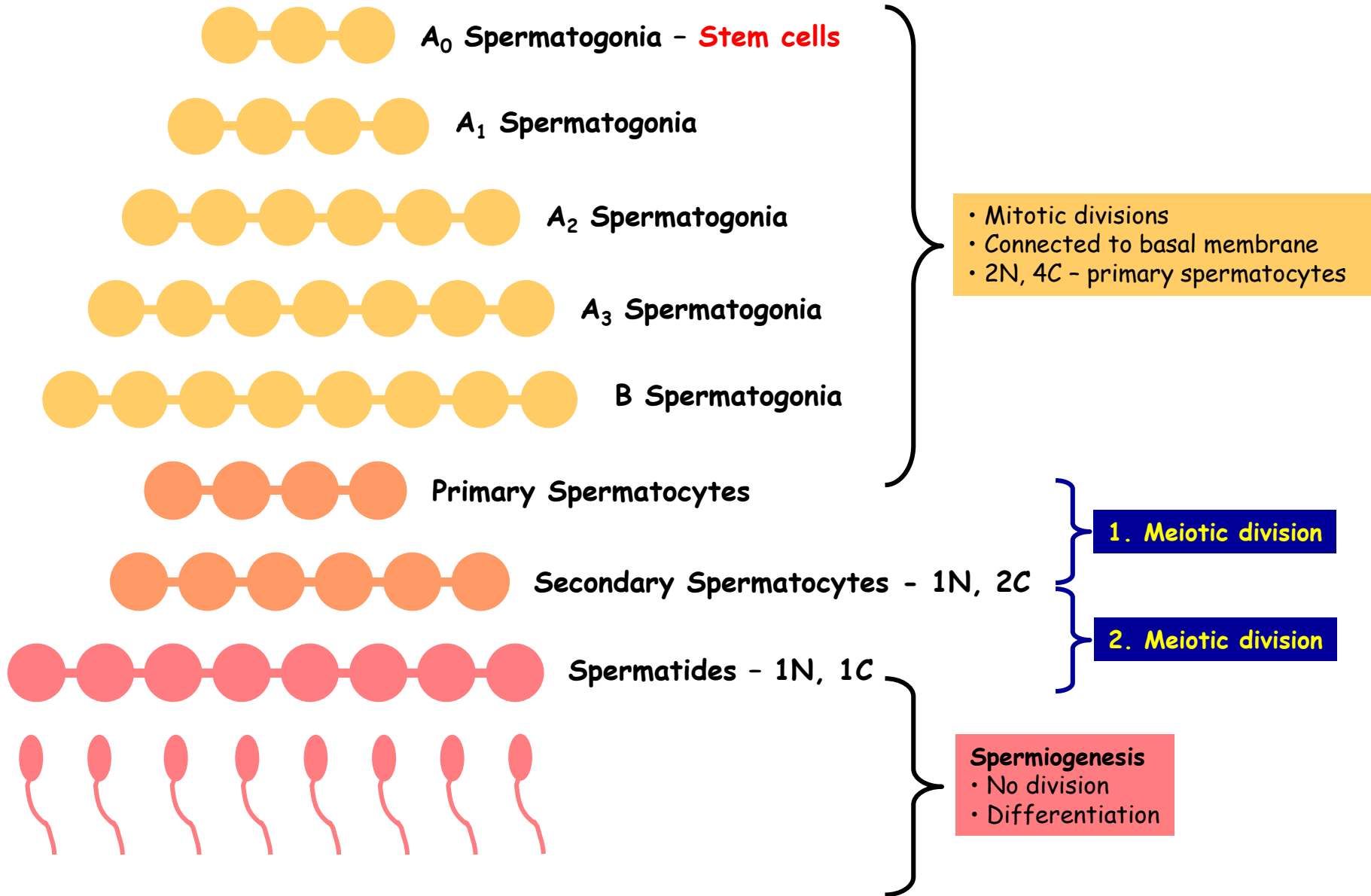


Spermatocytogenesis (mitotic)

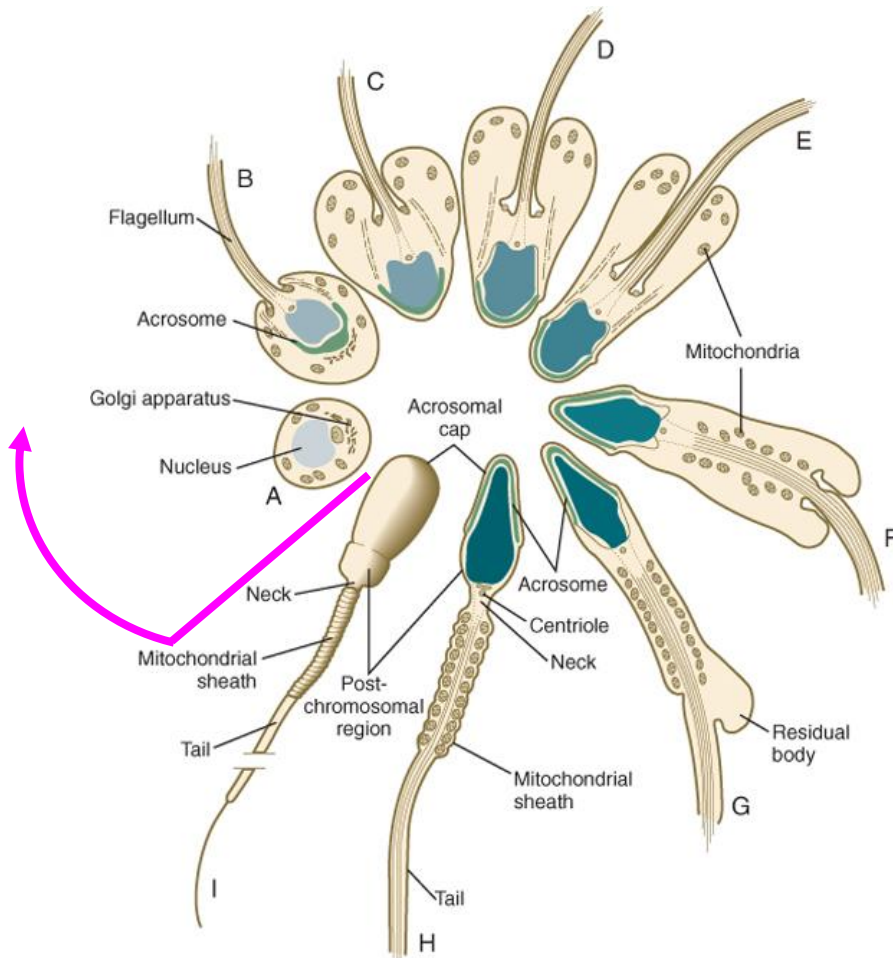
Meiotic phase

Spermiogenesis

Sperm cell development (3)



Sperm cell development (4) - Spermiogenesis

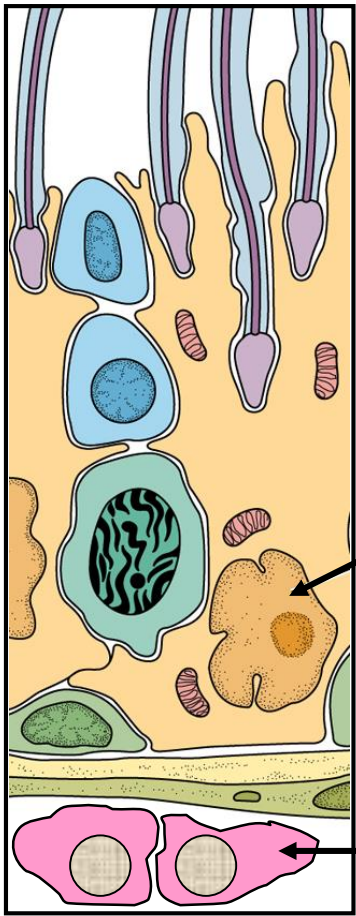


Histones to Protamines
Genome inactivation
Loss of cytoplasm

Sperm production

- 1 million sperms every hour
- Spermatogenesis takes ~70 days
- Transport through epididimis ~8-17 days
- Cyclic character
(Cycle of the seminiferous epithelium - 16 days
- the same developmental stage at the same place)

Sperm cell development (5) - Regulation

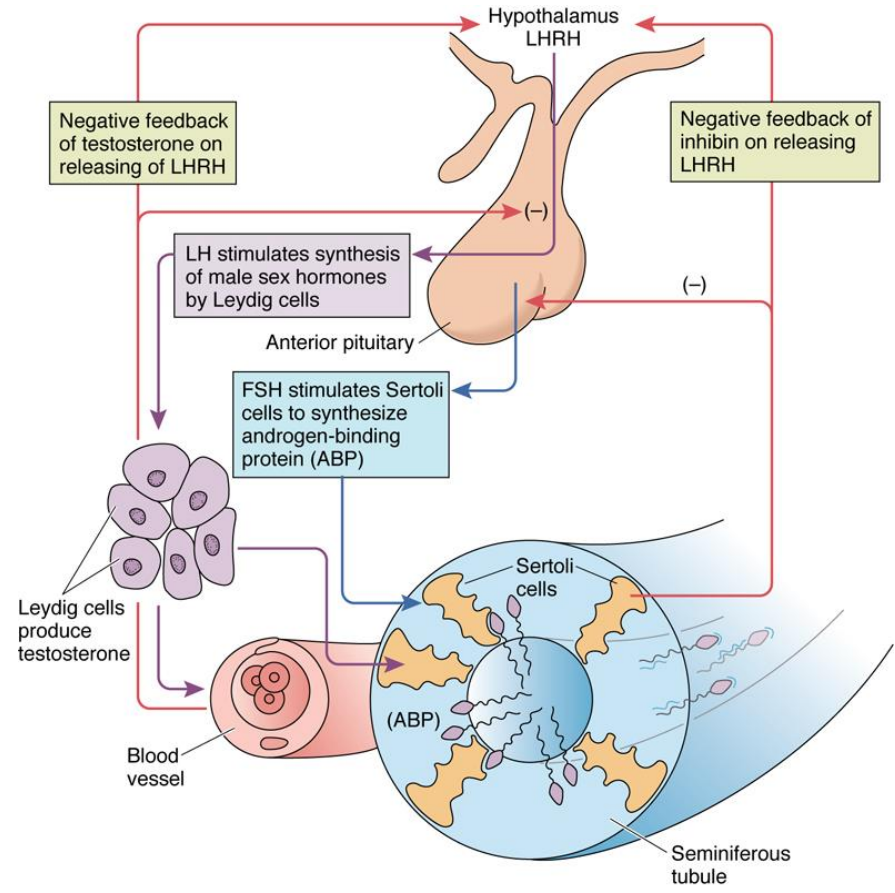


Sertoli cells

- Support, protect, and nourish
- Phagocyte
- Blood-testis barrier (zon. occlud.)
- Produce anti-mullerian hormone
- Produce fructose
- Produce inhibin (inh. FSH prod.)

Leydig cells

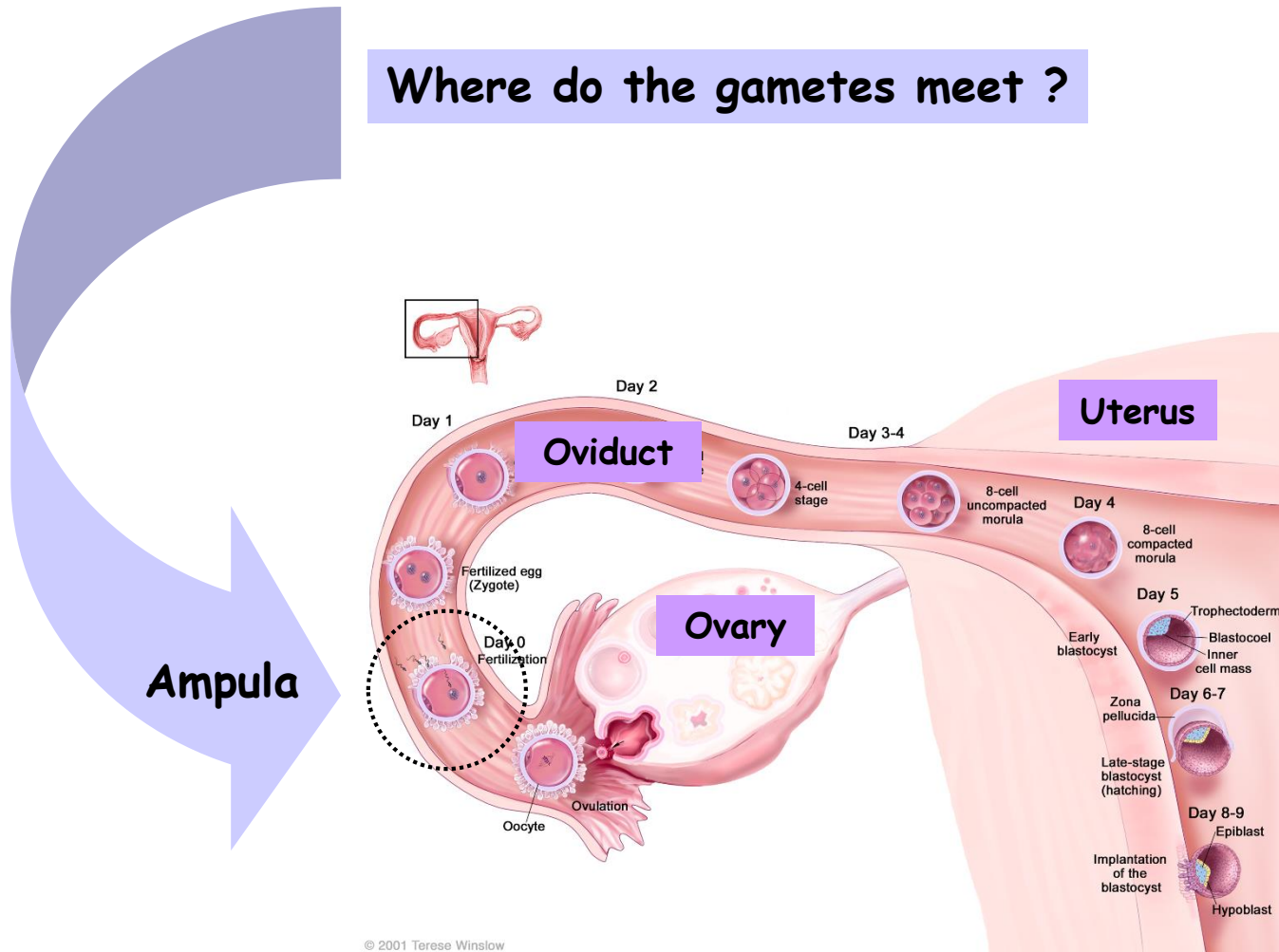
- In interstitium
- 10 % of testis
- Produce testosterone



Fertilization (1)

= the process that culminates in the union of one sperm nucleus with the egg nucleus within the activated egg cytoplasm

Where do the gametes meet ?



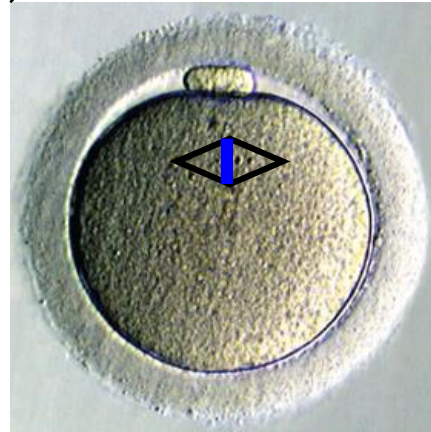
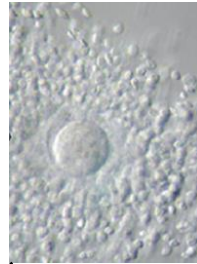
Fertilization (2)

Oocyte makes itself ready for being penetrated

LH surge

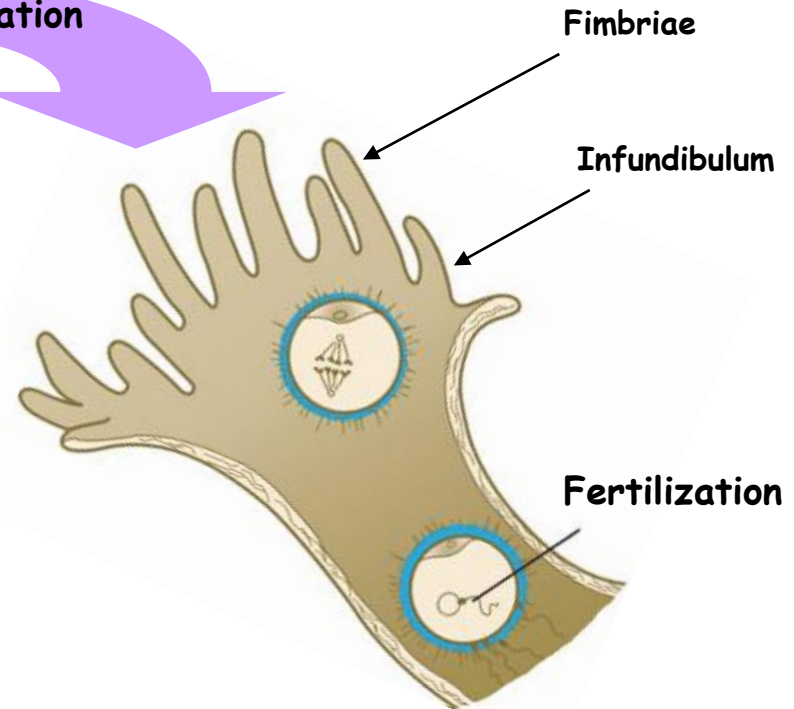


35-40 hrs



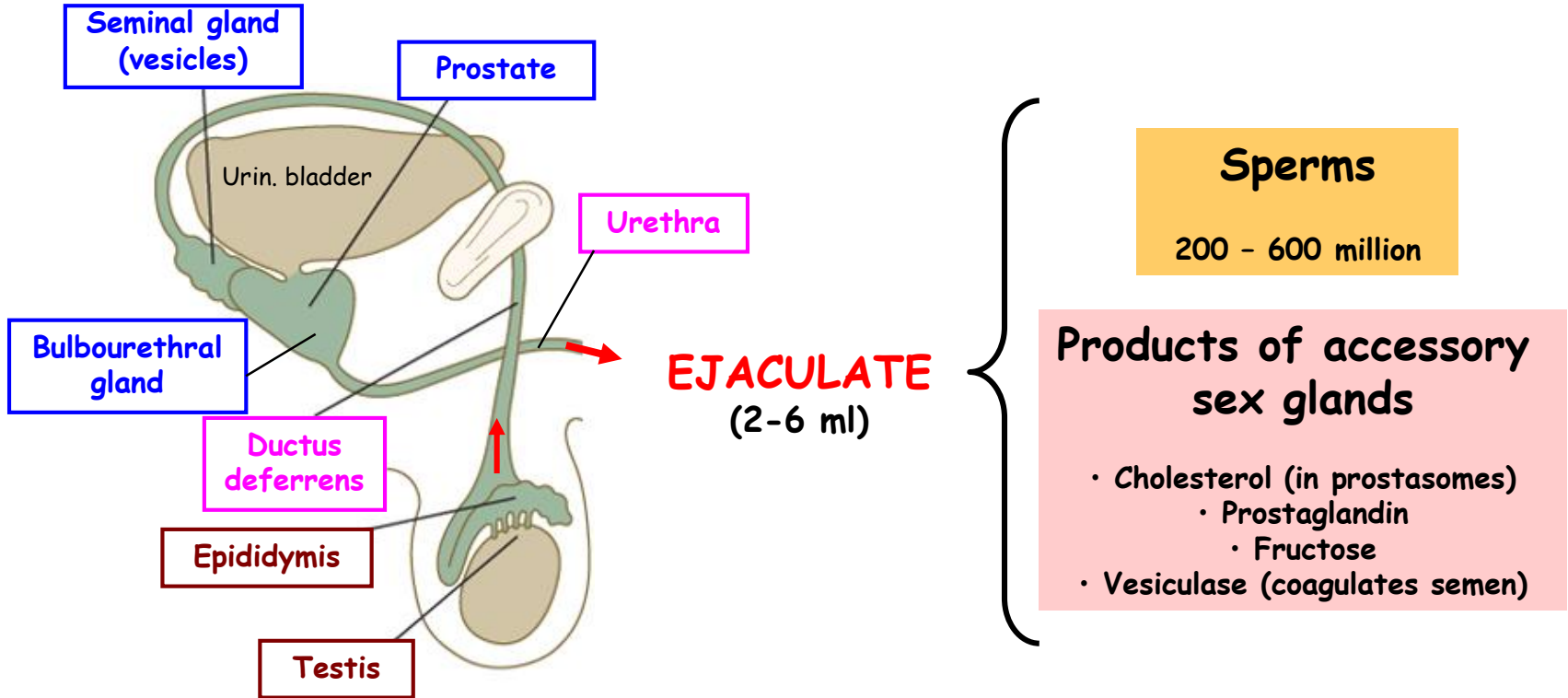
Oocyte is fertilizable for only 12 to 16 hours

Ovulation



Fertilization (3)

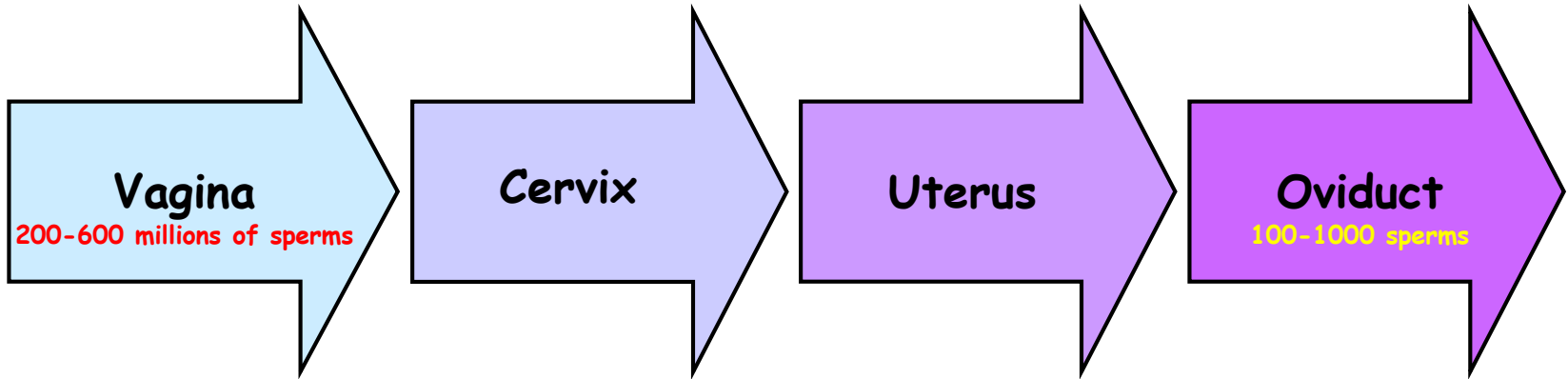
Travel of sperm to the site of fertilization



Fertilization (4)

Travel of sperm to the site of fertilization

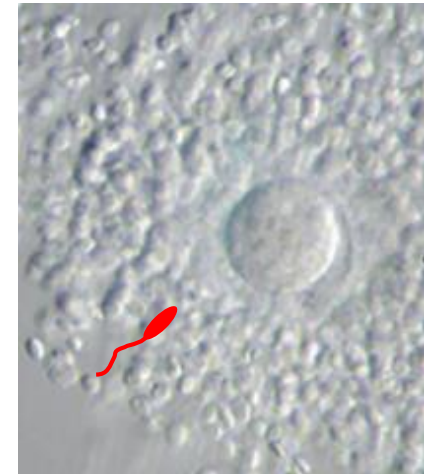
2 - 7 hours



- Acid environment
- Sperms move actively

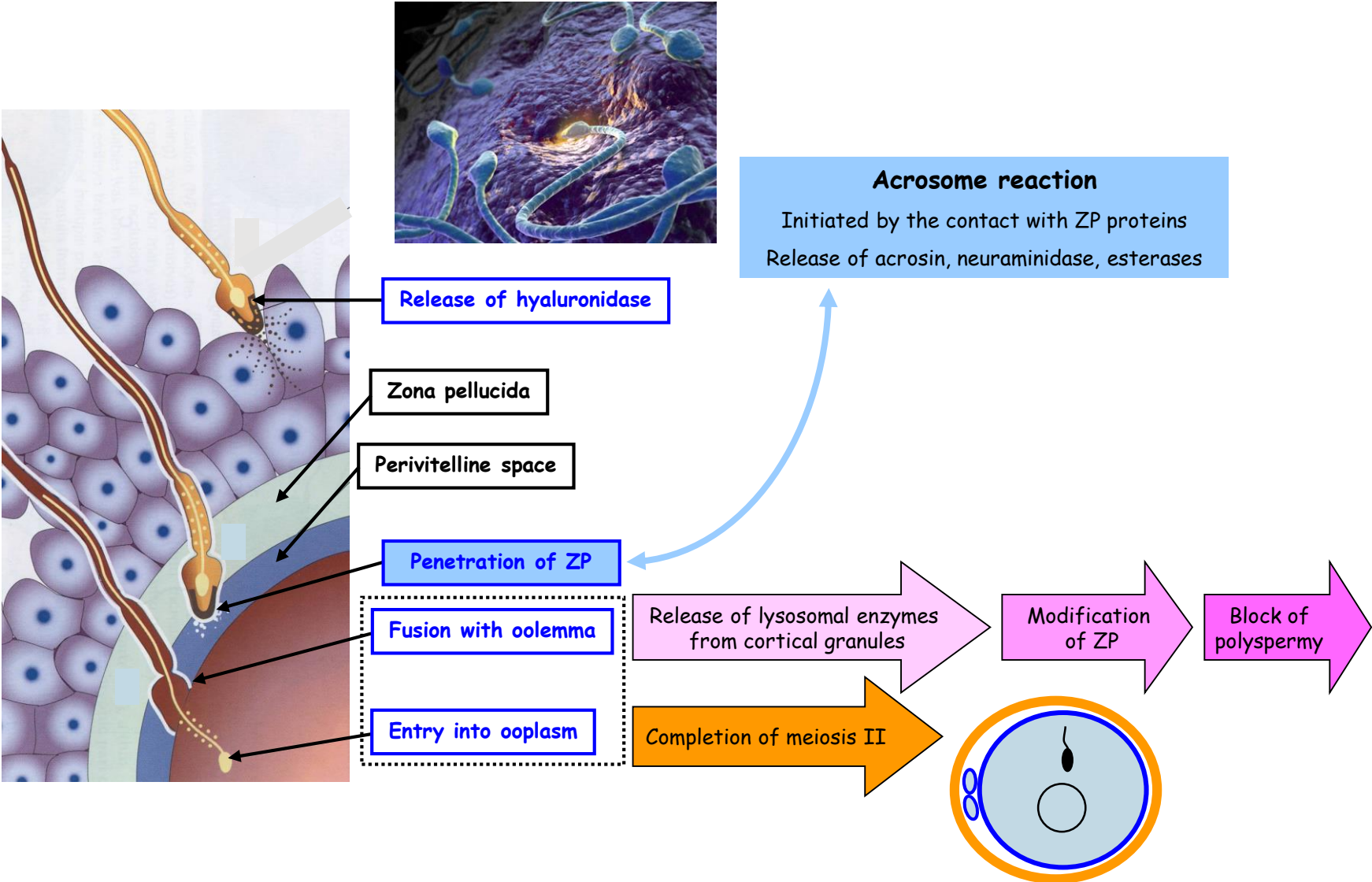
- Cleans sperm
- Cervical mucus stabilizes sperms
- Initiates **capacitation**

- Removal of glycoproteins from the head
- Change to composition of cell membrane
- Increase of motility



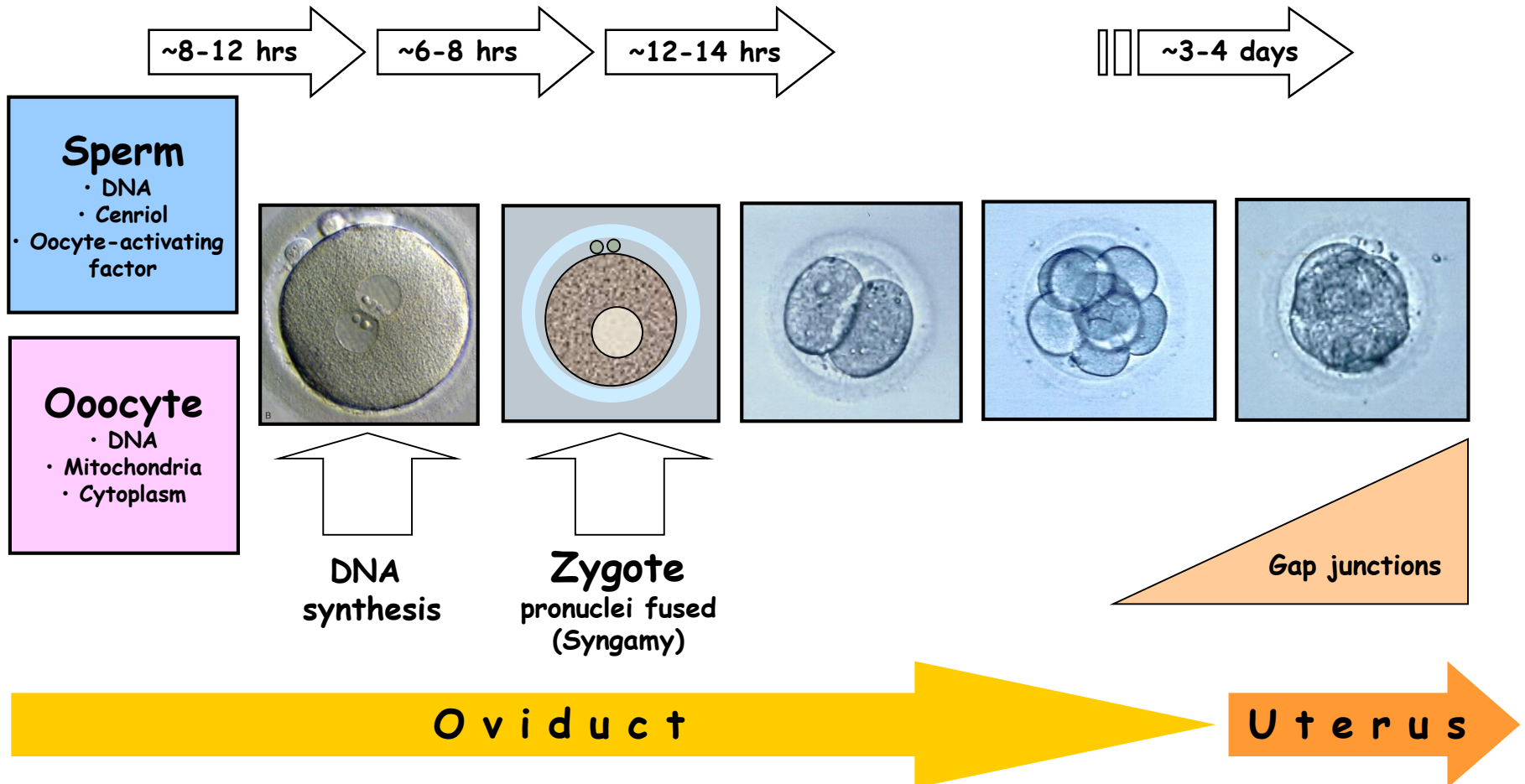
Fertilization (5)

Entry of sperm into the oocyte

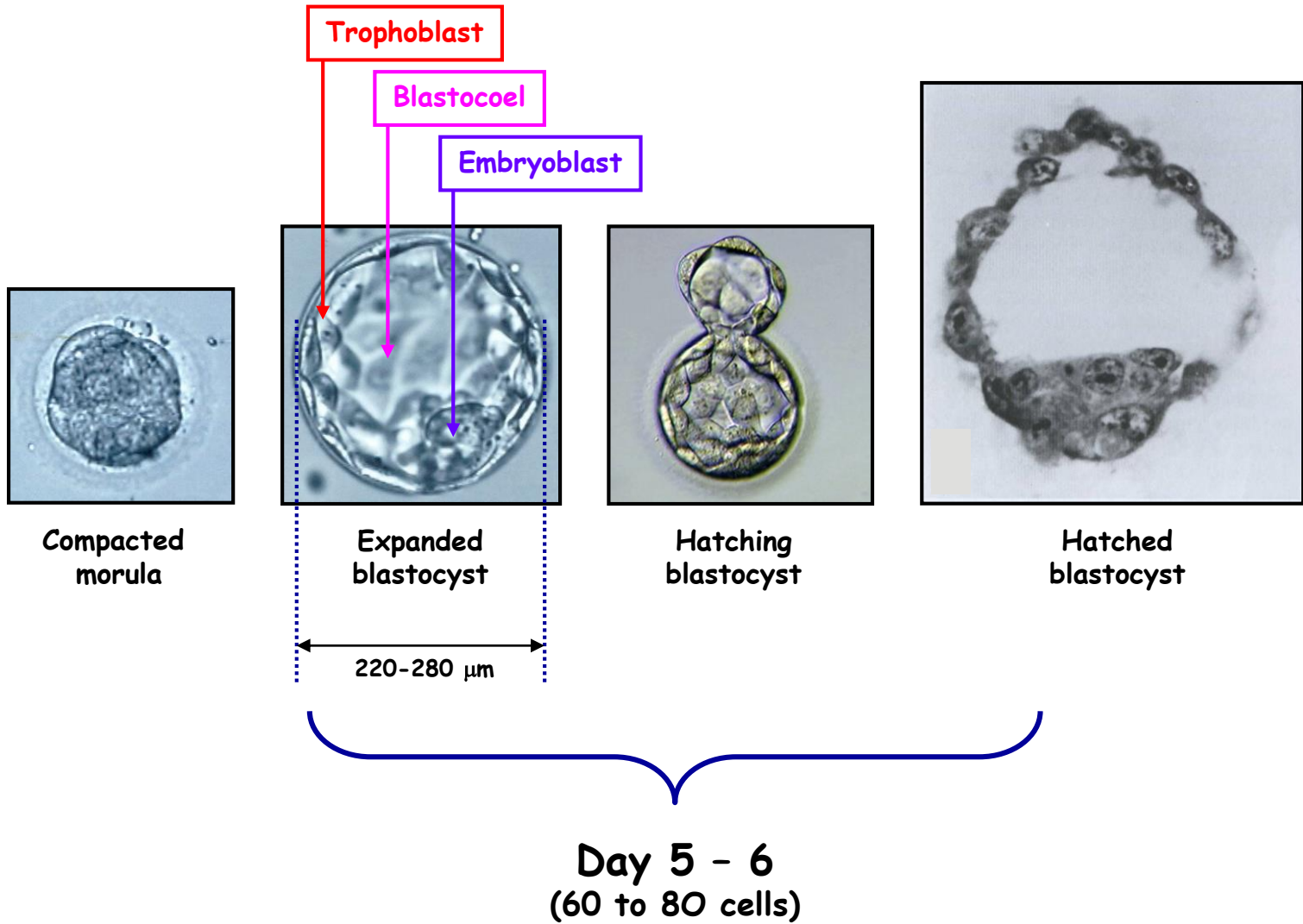


Fertilization (6)

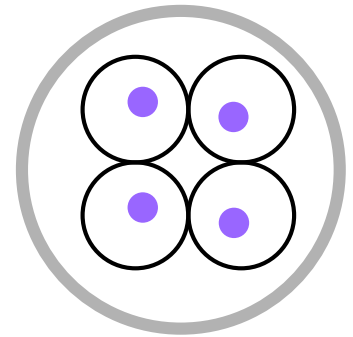
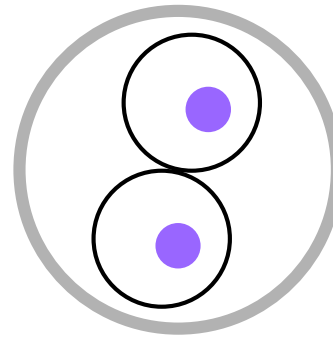
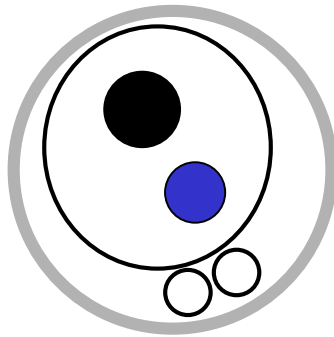
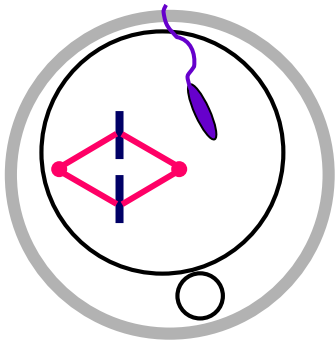
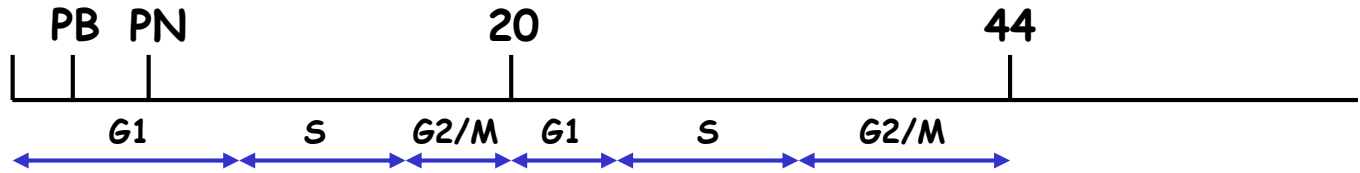
Zygote formation and the first cleavages



Blastocyst formation



A potency of oocyte cytoplasm



Translation of maternal mRNA

Translation of zygotic mRNA

Zygotic transcription

Activation of embryonal genome

Repression of transcription

Significance of „enhancers“

Activation of embryonal genome

It is not a single discrete event
(first signs occur in zygote, in man it reaches its
maximum in 4- to 8-cell embryo)

Two types of transcripts

Transcripts that replace
degraded maternal
mRNAs

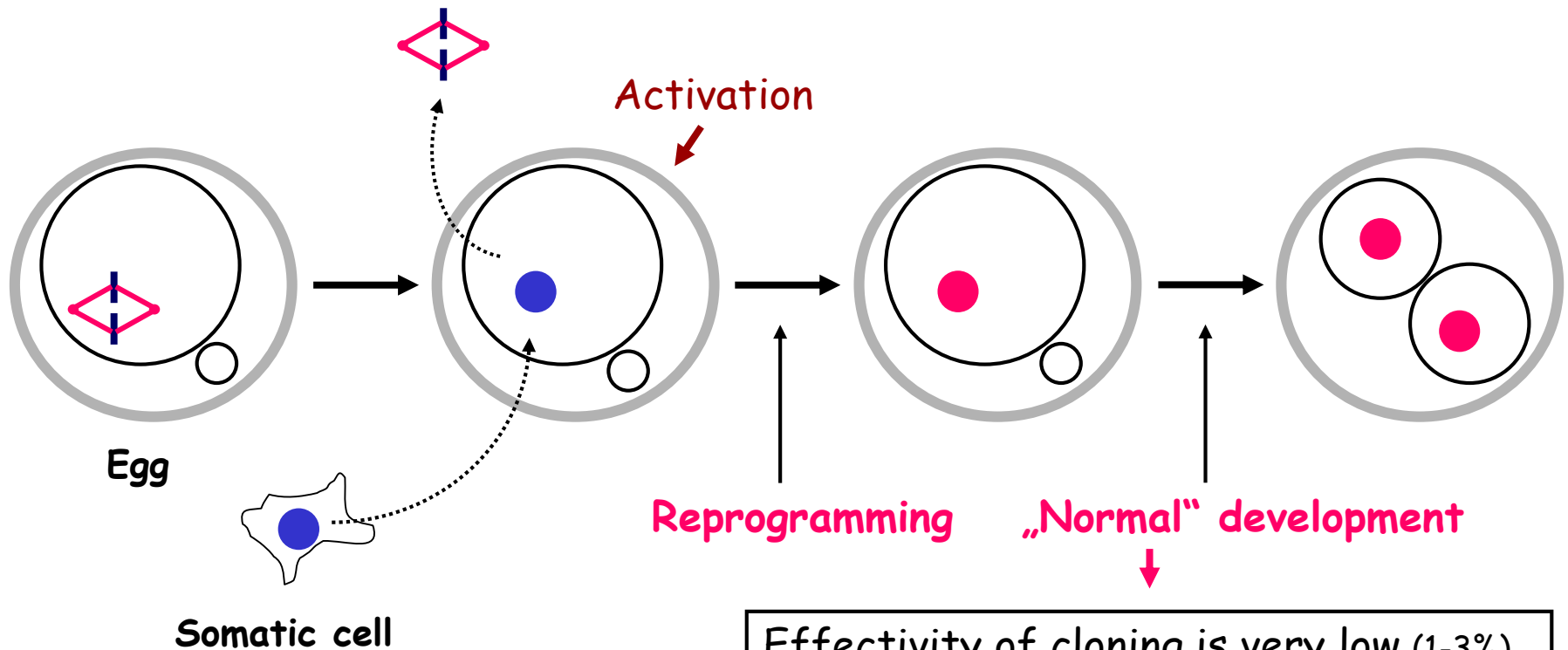
Novel transcripts that
underlie **new pattern of
gene expression**

It is „responsible“ for establishment of totipotency of blastomeres

&

It represents phenomenon known as genome **REPROGRAMMING**

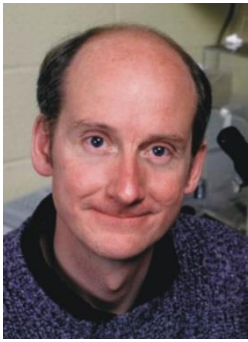
Nuclear transfer (cloning) - principle



Effectivity of cloning is very low (1-3%)

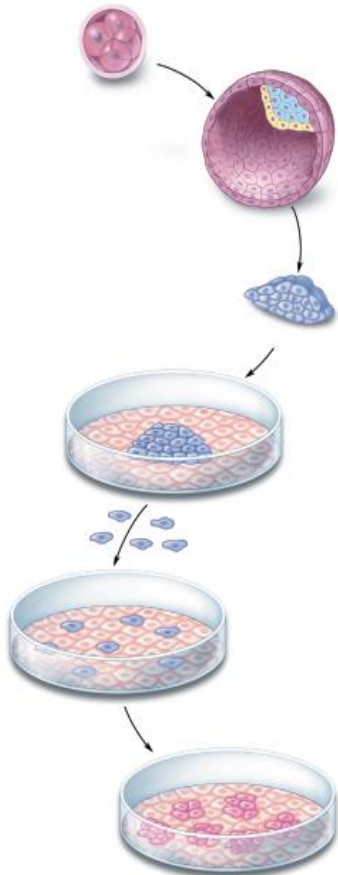
Reprogramming is slow and most likely incomplete (as the result, gene expression is often abnormal)

Effectivity of reprogramming depends on many factors (type of somatic cells, position in cell cycle phase, ...)



Human Embryonic Stem (hES) Cells

(Thompson et al, 1998)

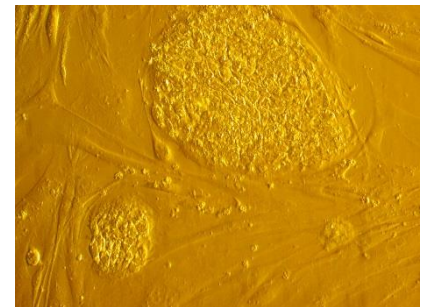
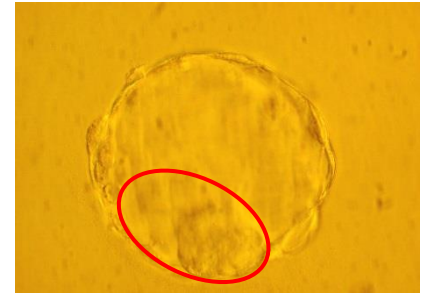


Early embryo at blastocyst stage

Isolated embryoblast (ICM - Inner Cell Mass)

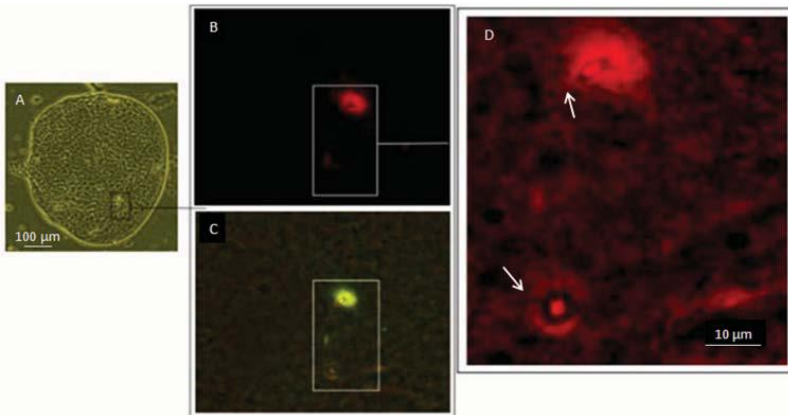
Isolated embryoblast after placing to *in vitro* conditions (+ feeder cells + FGF2)

Propagation in culture by enzymatic disaggregation (repeated passaging)

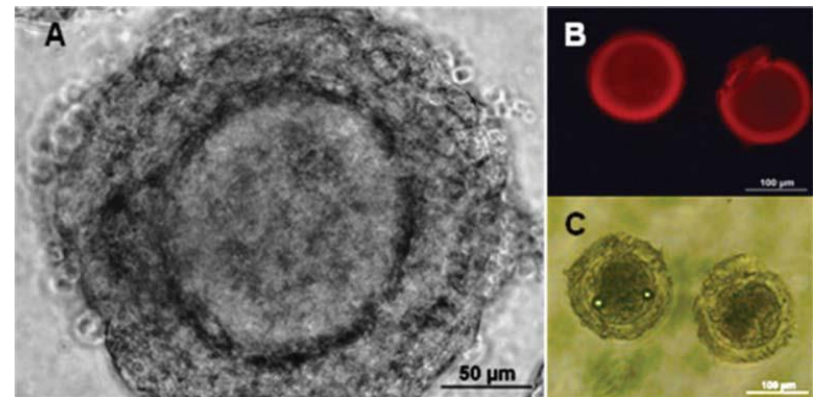


Derivation of postmeiotic germ cells from hESC

Prof. Harry Moore, University of Sheffield, 2009



- B) C-KIT
- C) I-97 antigen
- D) Cells with condensed chromatin and signs of flagellum



Structures that are highly reminiscent to oocyte-granulosa complexes (zona pellucida is not developed)

Thank you for your attention !

**Questions and comments at:
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