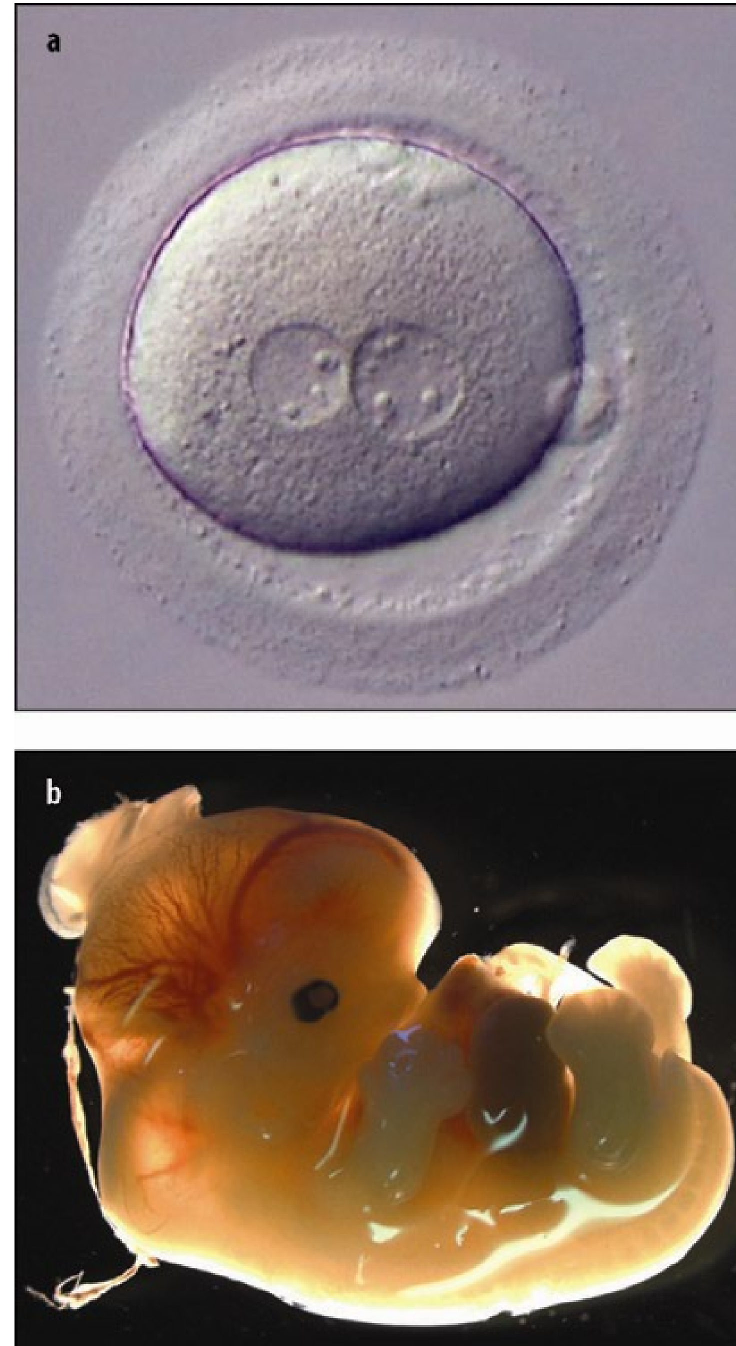
Embryology

Introduction



What is embryology?

- Study of the developing embryo (embryogenesis).
- What is an embryo?
  - Multicellular
  - Diploid
  - Fertilized egg to hatching, birth or germination

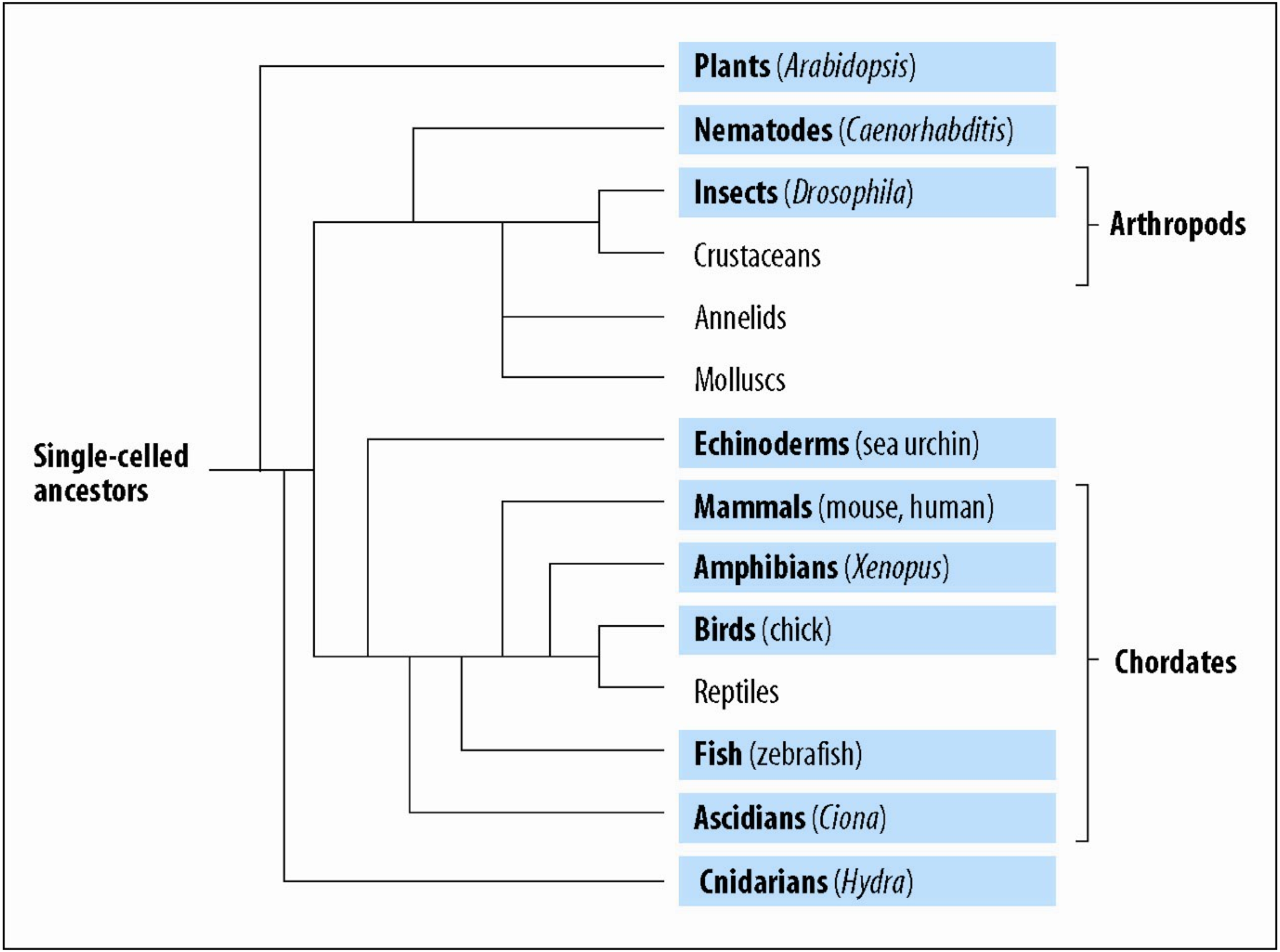
Is embryology the same as developmental biology?

- Embryology is part of Developmental Biology
- Developmental biology includes developmental processes after the embryonic stages.
  - Metamorphosis in insects
  - Development of sex specific characteristics
  - Repair of damaged tissues and organs
  - Regeneration
  - Cancer and tumors – development out of control

How are embryos studied?

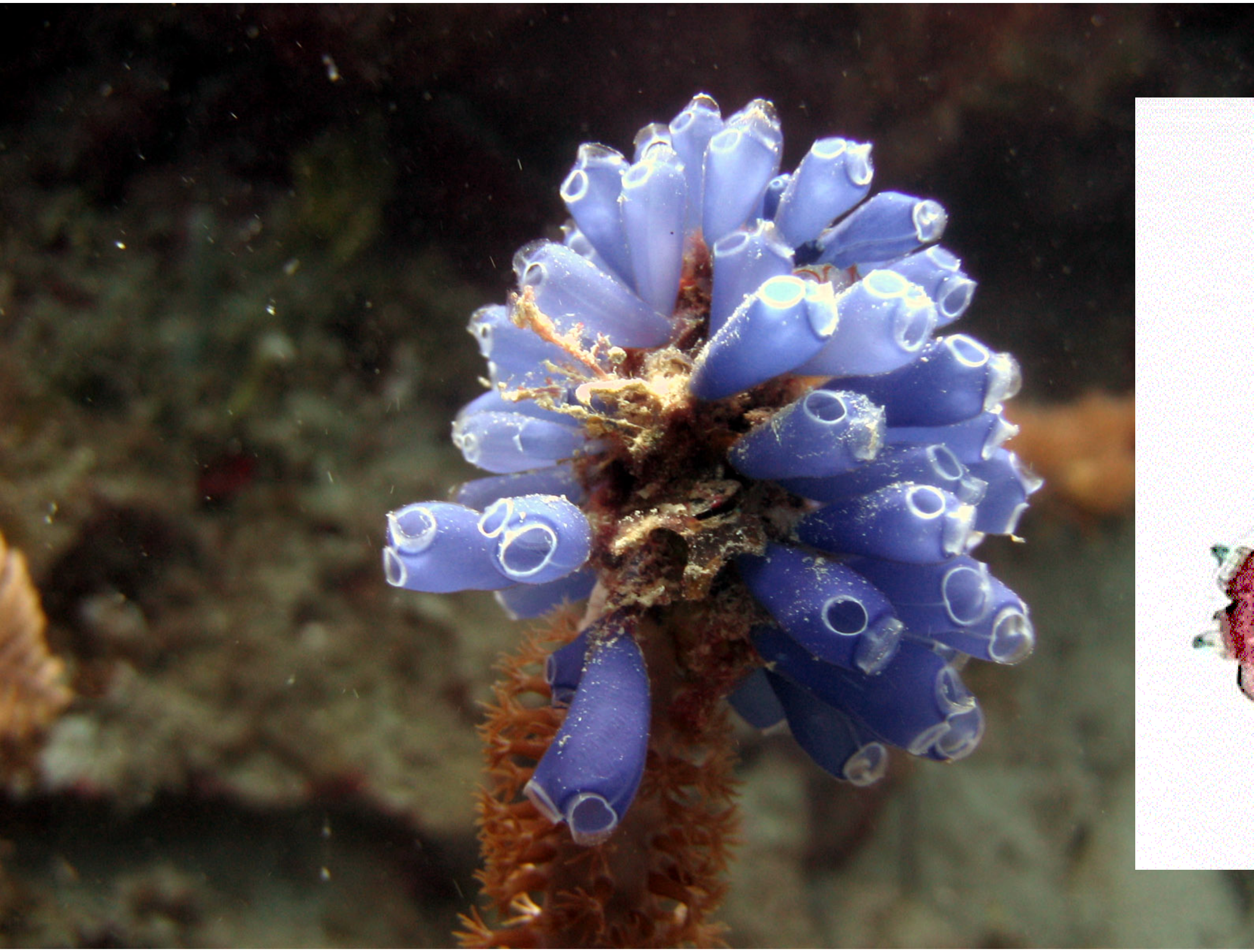
- Anatomically
  - Traces the fates of cells and tissues during embryogenesis
- Experimentally
  - Support hypotheses on how and why embryonic events occur.
- Genetically
  - How information encoded in DNA controls embryogenesis

Fig. 1.11



Single-celled ancestors
Plants (*Arabidopsis*)
Nematodes (*Caenorhabditis*)
Insects (*Drosophila*)
Crustaceans
Annelids
Molluscs
Echinoderms (sea urchin)
Mammals (mouse, human)
Amphibians (*Xenopus*)
Birds (chick)
Reptiles
Fish (zebrafish)
Ascidians (*Ciona*)
Cnidarians (*Hydra*)
Arthropods
Chordates

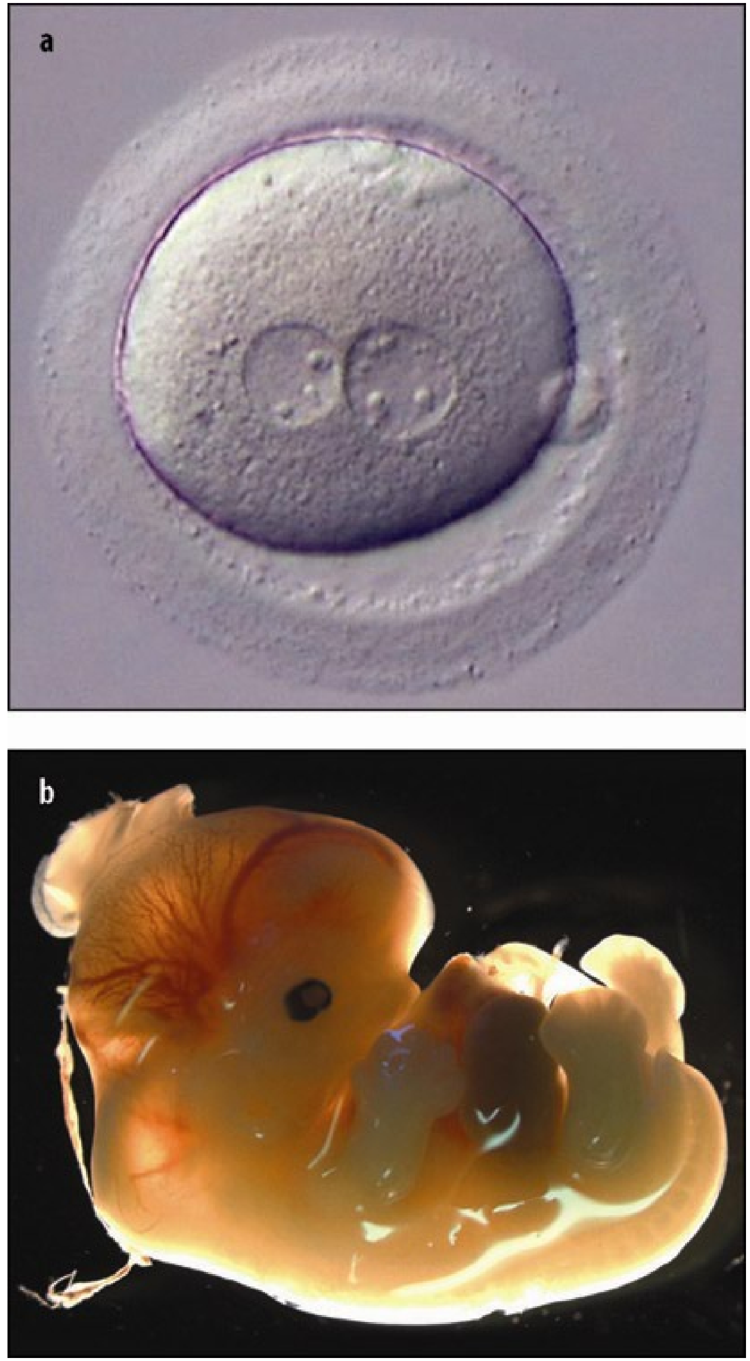
Tunicate



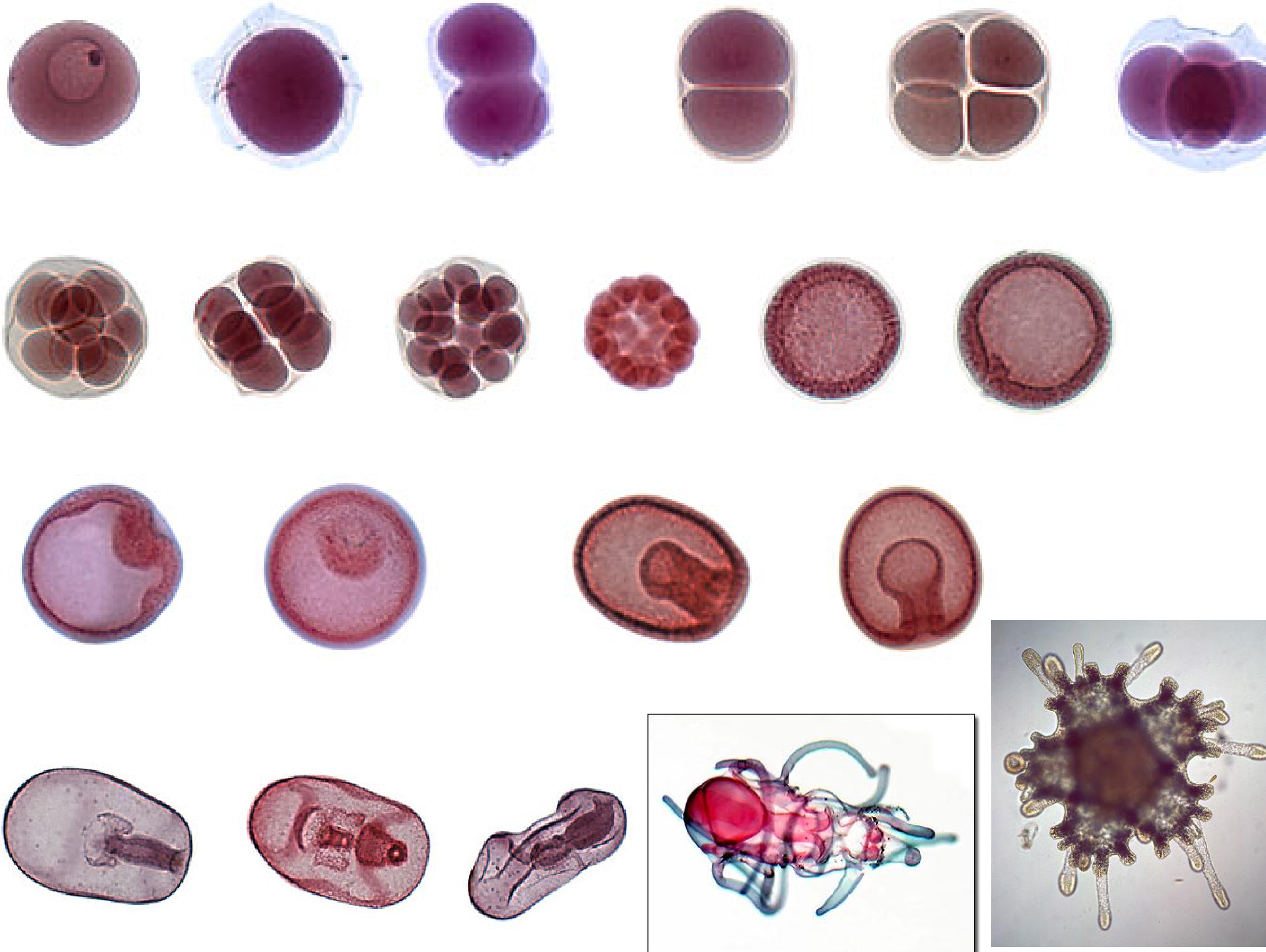
Adult

Larvae

Fig. 1.1



Zygote to Adult



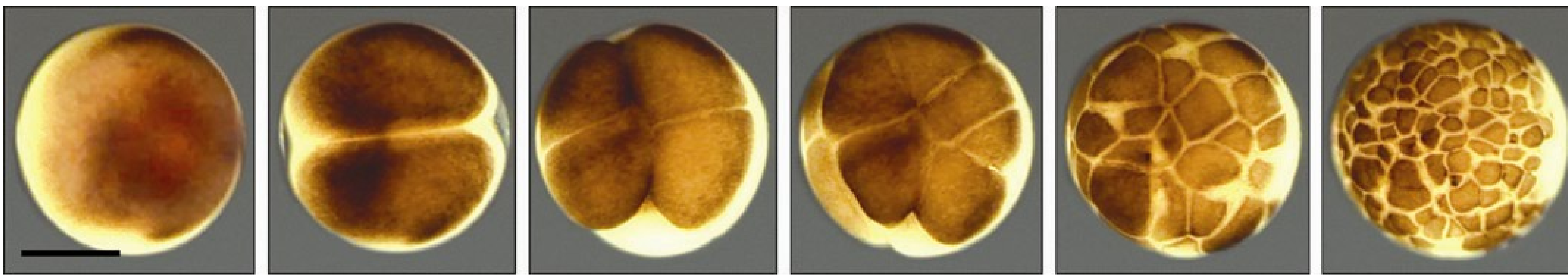
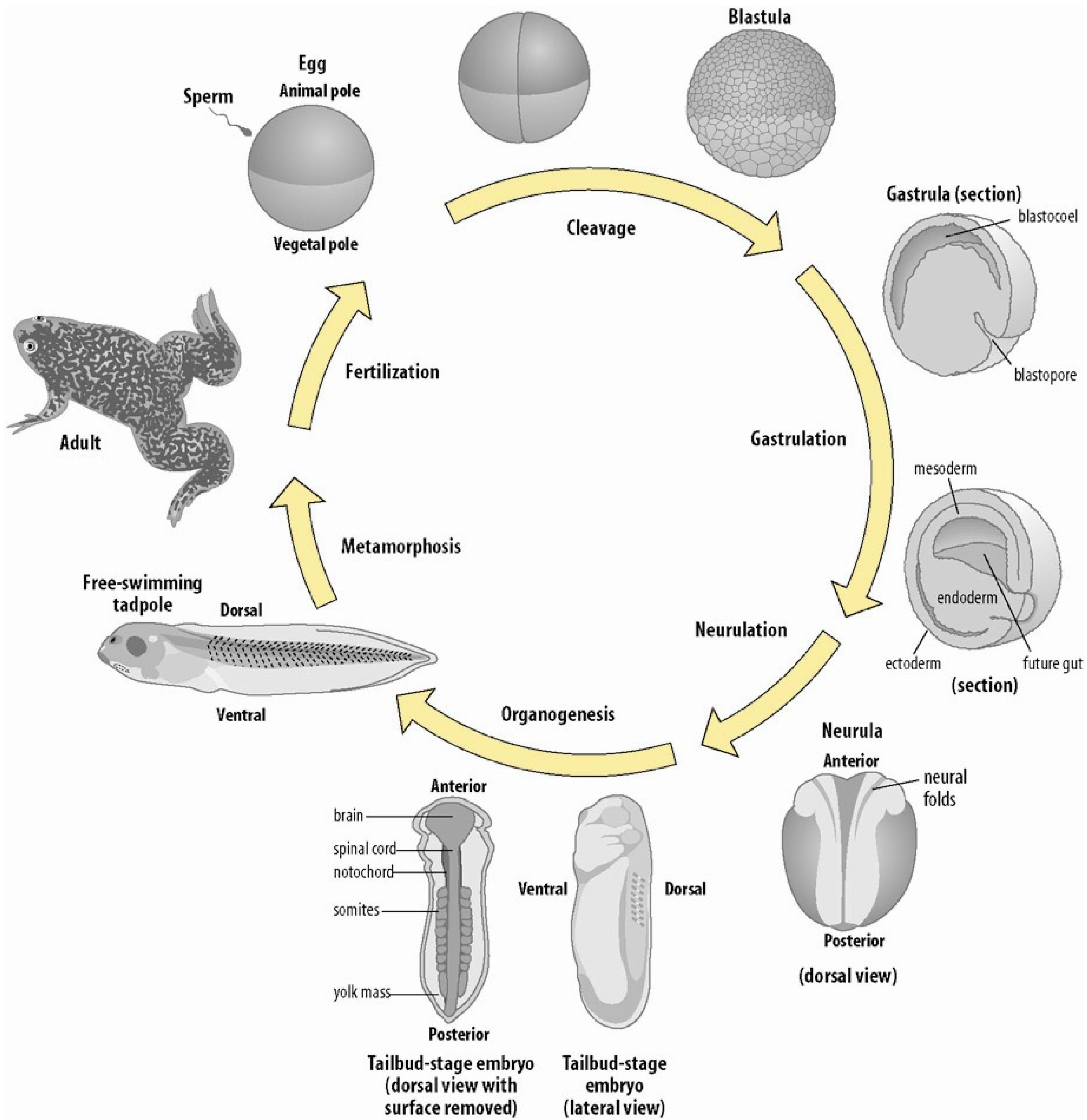


Fig. 1.14



Egg
Animal pole
Sperm
Vegetal pole
Blastula
Cleavage
Gastrula (section)
blastocoel
blastopore
Gastrulation
mesoderm
endoderm
ectoderm
future gut
(section)
Neurulation
Neurula
Anterior
neural folds
Posterior
(dorsal view)
Organogenesis
Anterior
brain
spinal cord
notochord
somites
yolk mass
Posterior
Tailbud-stage embryo (dorsal view with surface removed)
Ventral
Dorsal
Tailbud-stage embryo (lateral view)
Free-swimming tadpole
Dorsal
Ventral
Metamorphosis
Adult
Fertilization

Box 1A

Fig. 1.2

Major Questions in Embryology

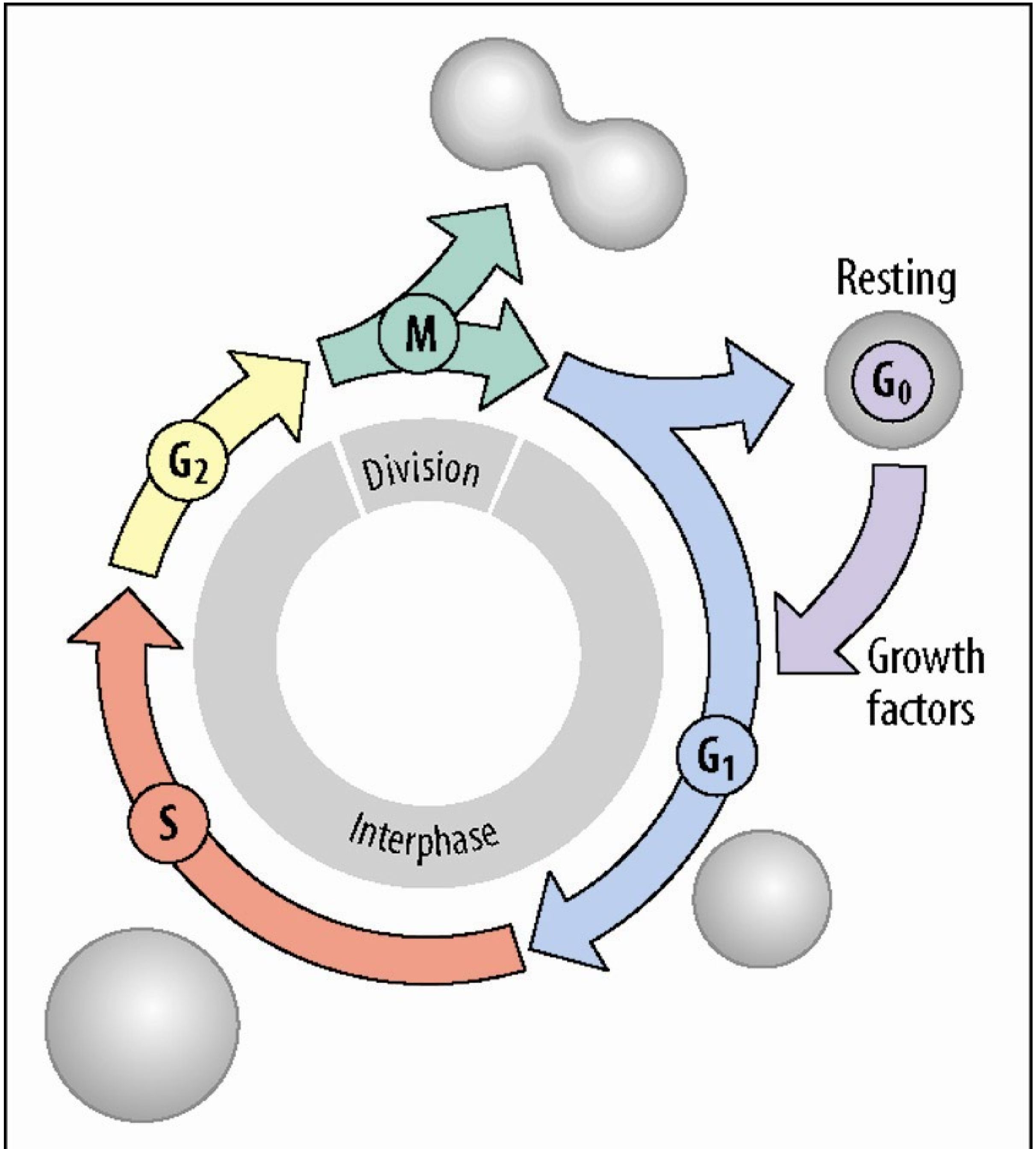
Growth – mitosis is controlled to produced the correct number of cells.

Differentiation – single cell, with single genome produces hundreds of cell types.

Morphogenesis – cell move during development.

Reproduction – embryogenesis starts with information encoded in the egg cell.

Box 1B



Epigenesis vs. Preformation

- Preformation
  - complete form present in egg or sperm in miniature
- Epigenesis
  - embryos are formed *de novo*

Fig. 1.4

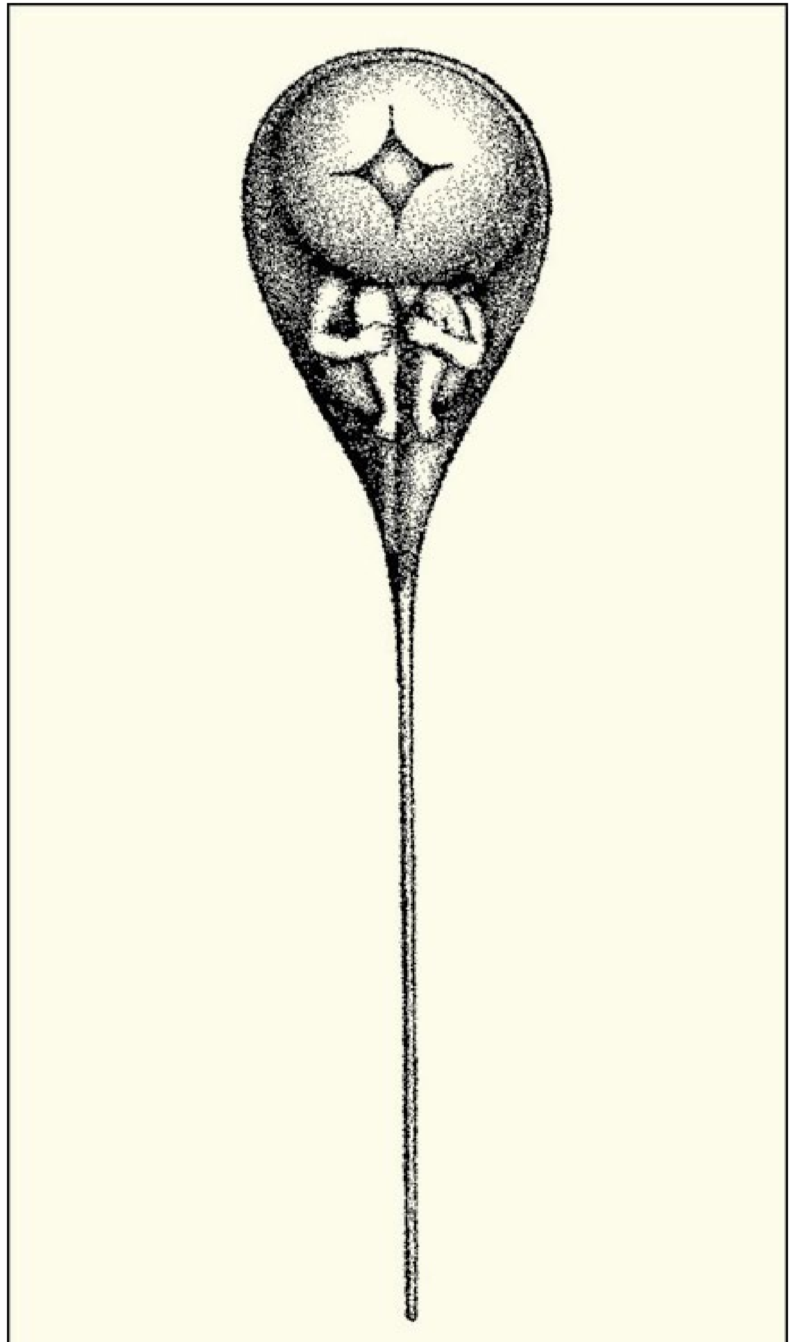
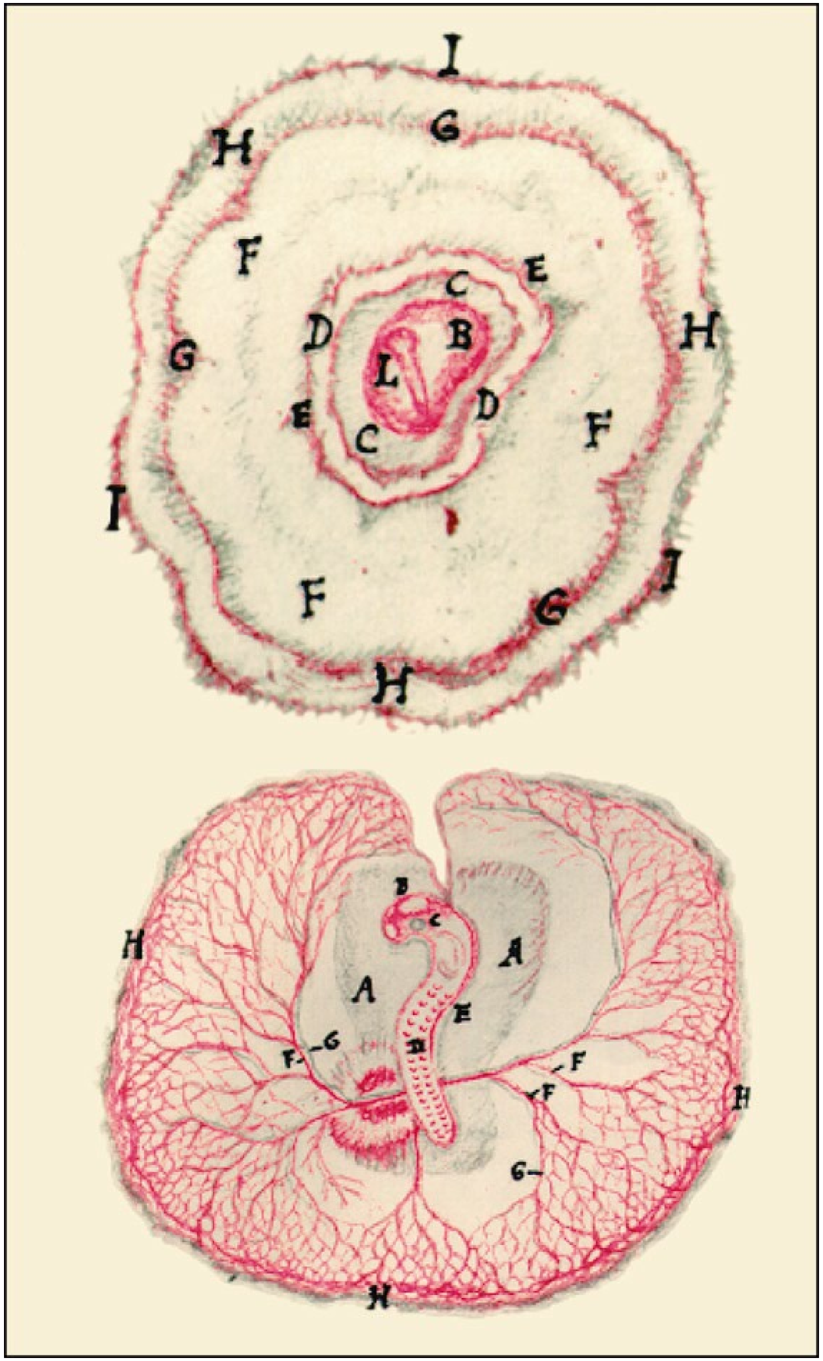


Fig. 1.3



Christian Pander (1820's)

- Primary Germ Layers
- Chick embryo forms three layers of cells that give rise to specific organ systems.

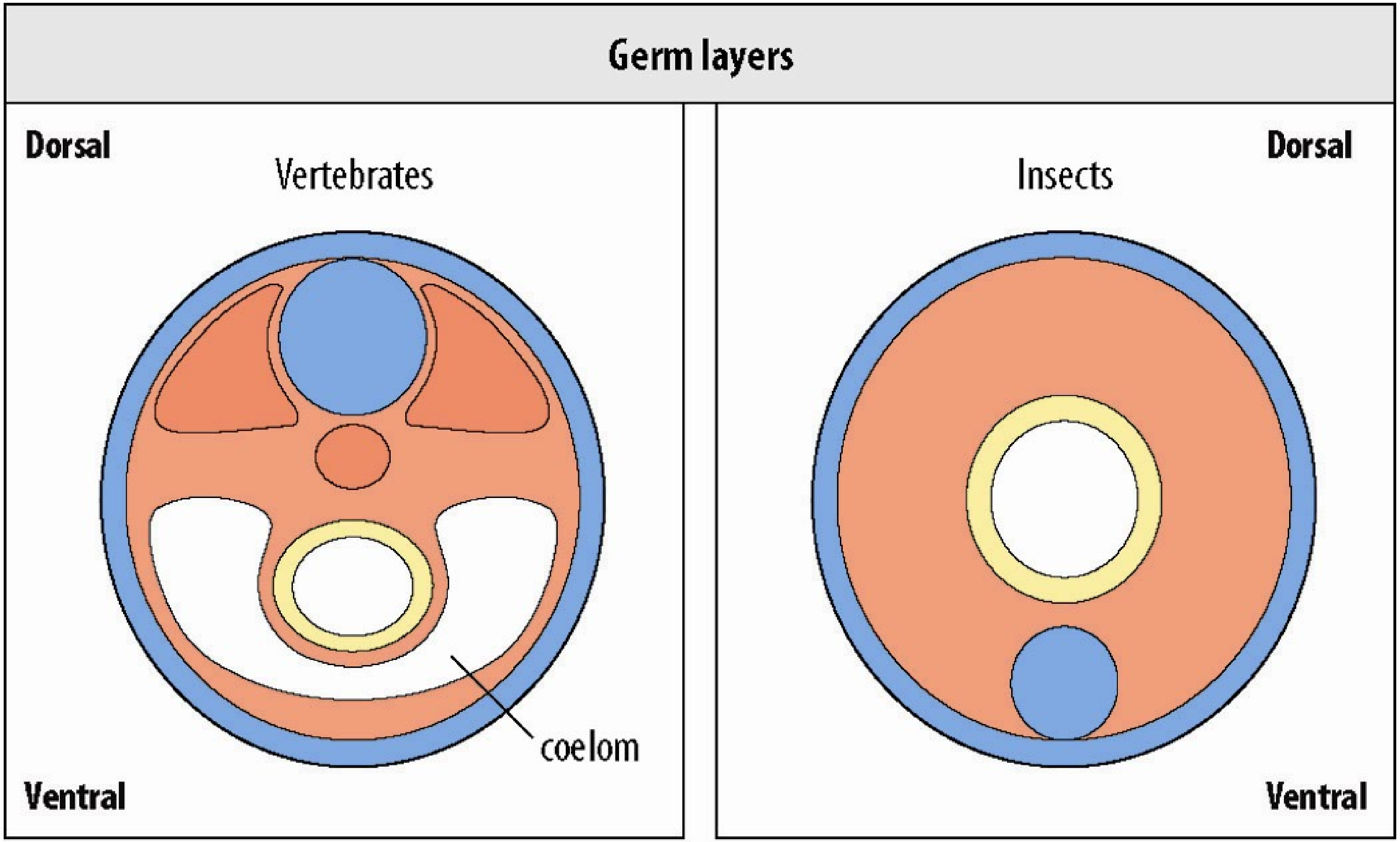
Diploblastic

- Jellyfish, hydra
- Only two primary germ layers
  - Ectoderm and endoderm

Triploblastic

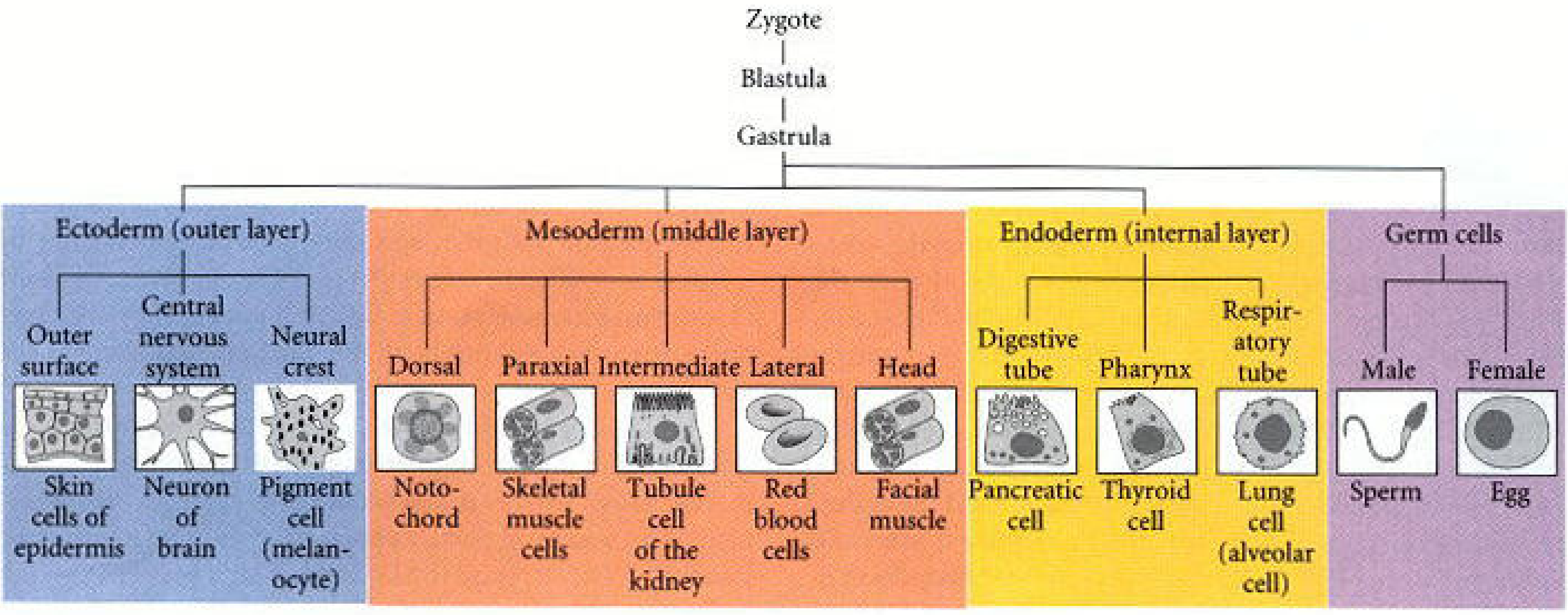
- Most animals
- Three primary germ layers
  - Ectoderm – outer layer
    - Skin, nervous system
  - Endoderm – inner layer
    - Digestive tract, lungs
  - Mesoderm – middle layer
    - Muscles, blood, heart, kidneys, bones, gonads

Box 1C



Germ layers	Organs	
Endoderm	gut, liver, lungs	gut
Mesoderm	skeleton, muscle, kidney, heart, blood	muscle, heart, blood
Ectoderm	epidermis of skin, nervous system	cuticle, nervous system

Cell Differentiation



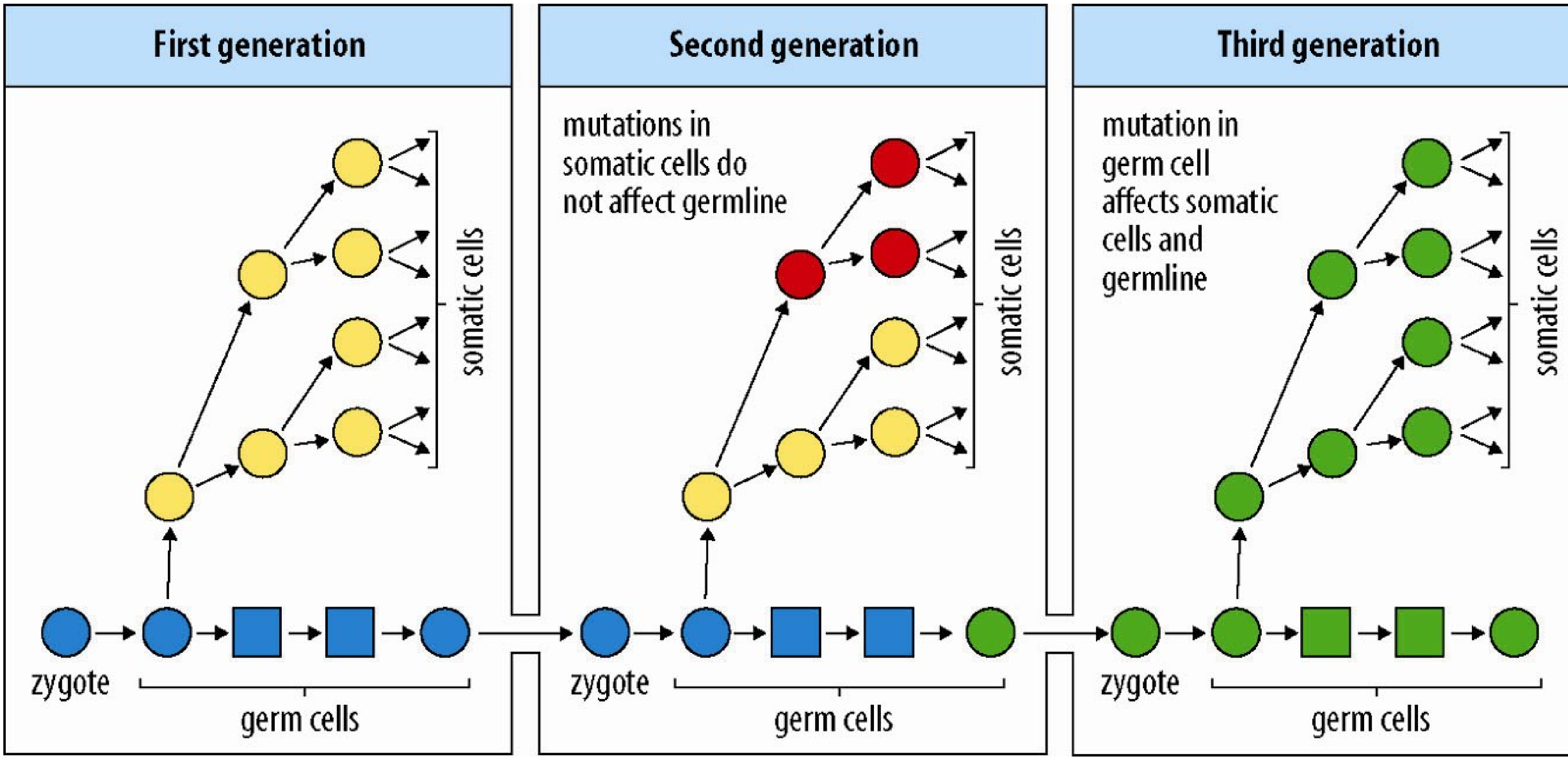

First generation
somatic cells
zygote
germ cells
Second generation
mutations in
somatic cells do
not affect germline
somatic cells
zygote
germ cells
Third generation
mutation in
germ cell
affects somatic
cells and
germline
somatic cells
zygote
germ cells

Fig. 1.5

Determinants vs. Regulation

Determinants – factors distributed in egg asymmetrically determine cell fate.

Regulation – cell interactions determine cell fate.

Weismann's Nuclear Determinant

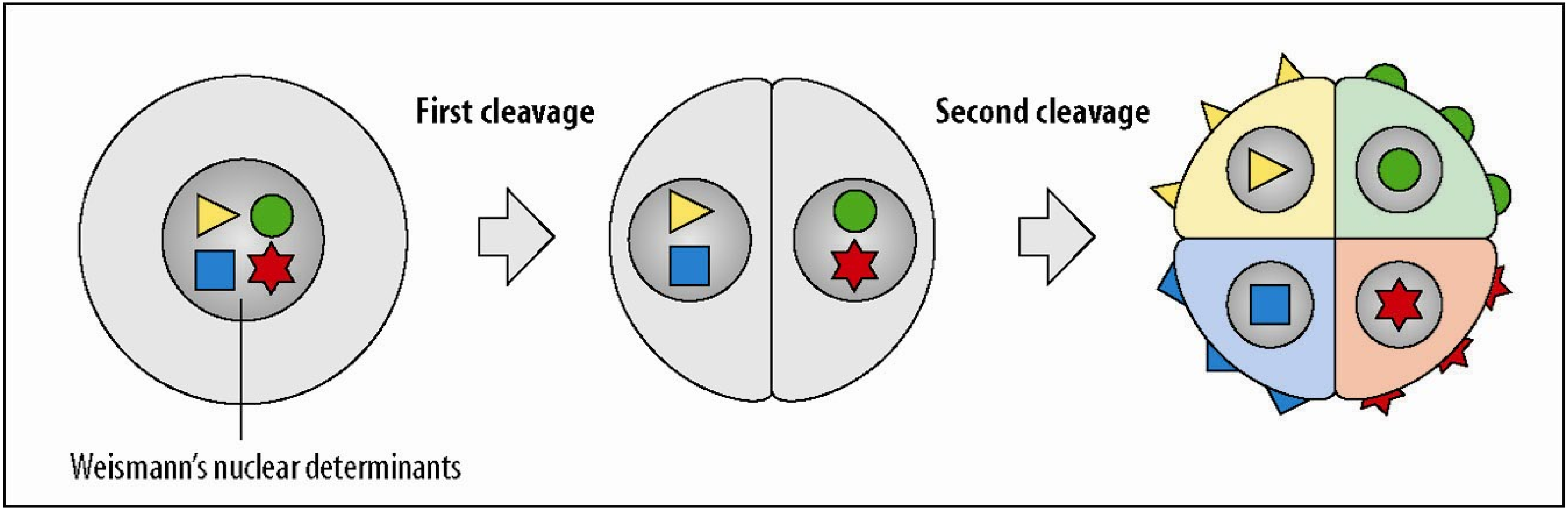


Fig. 1.6

Roux Mosaic Development

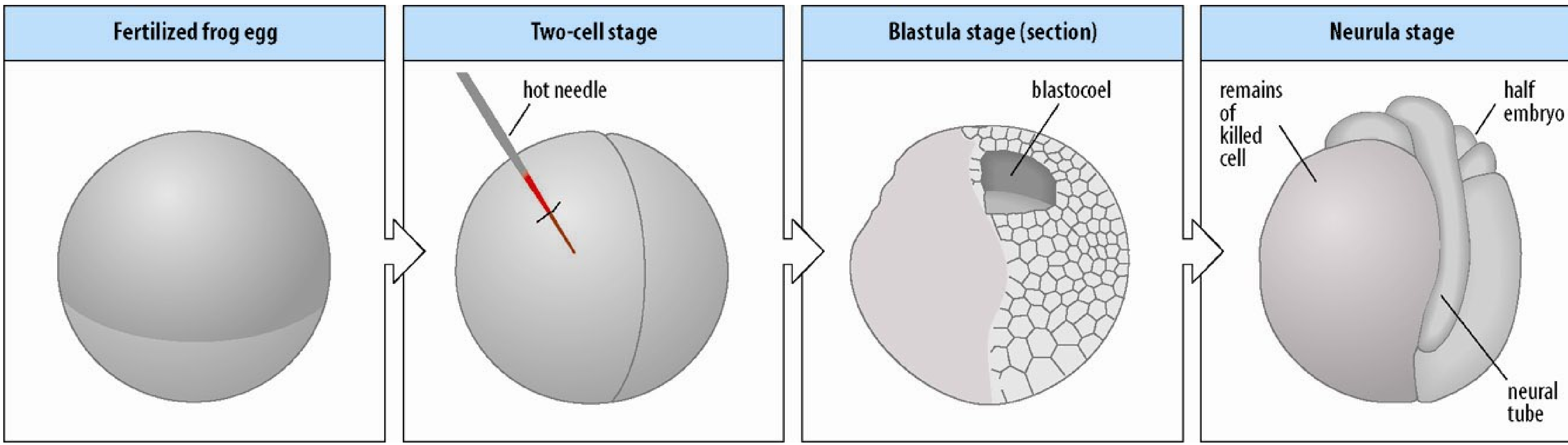
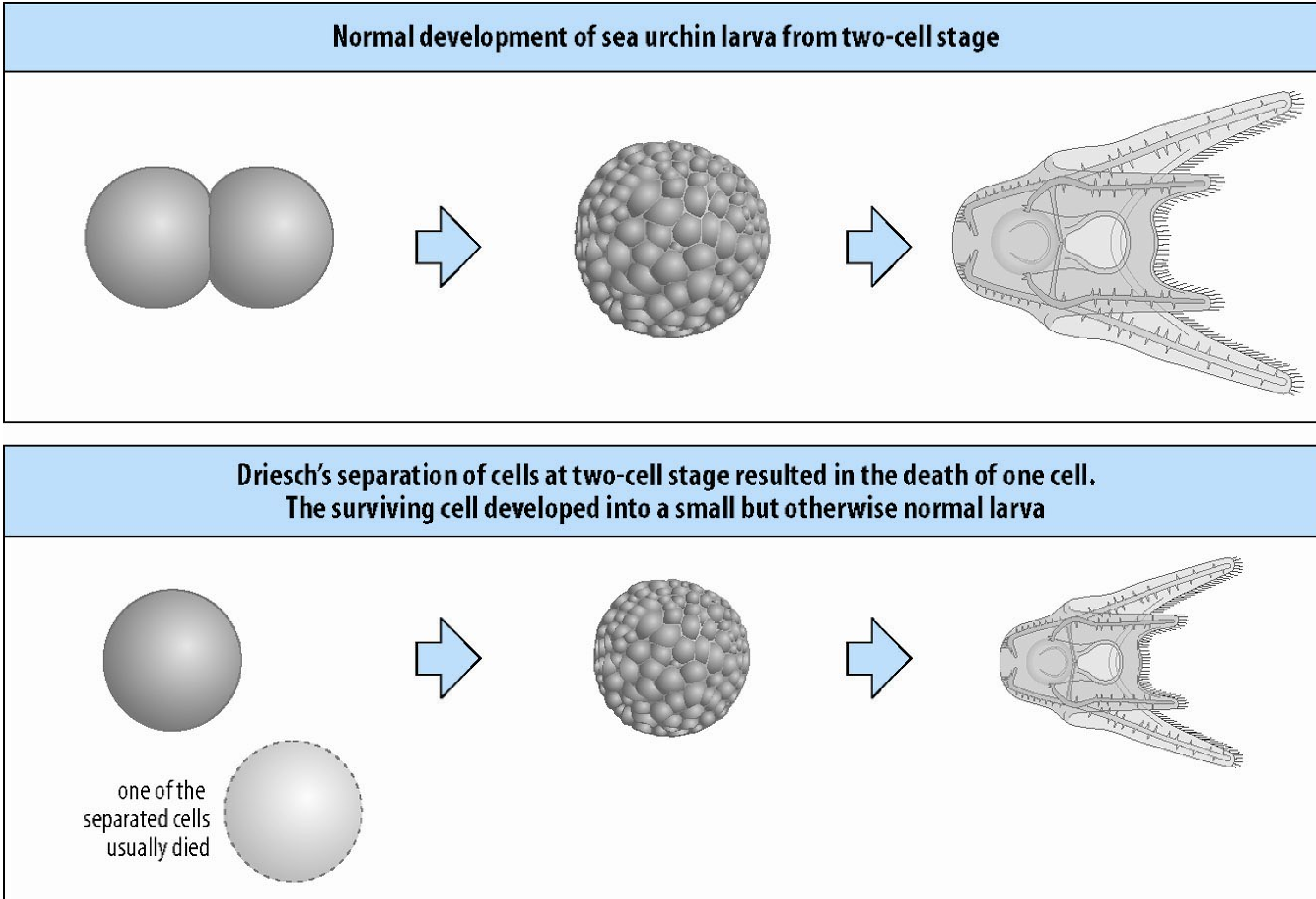


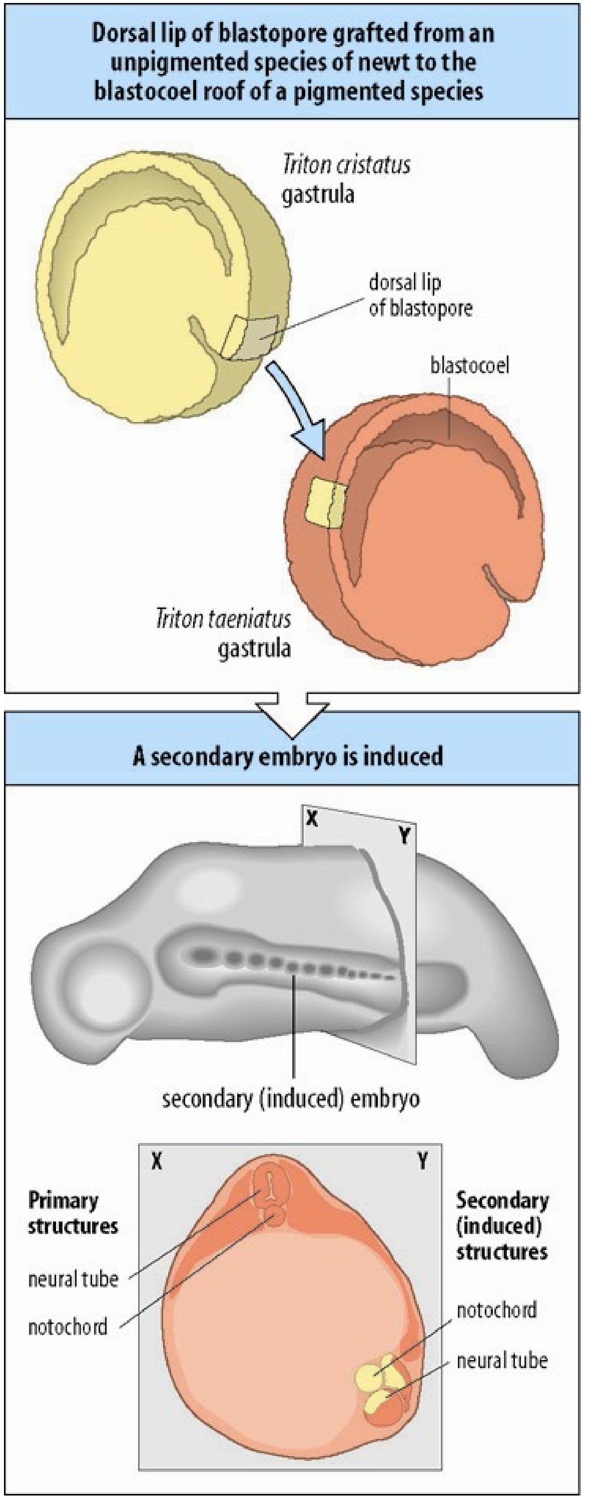
Fig. 1.7

Driesch – contradicts Roux



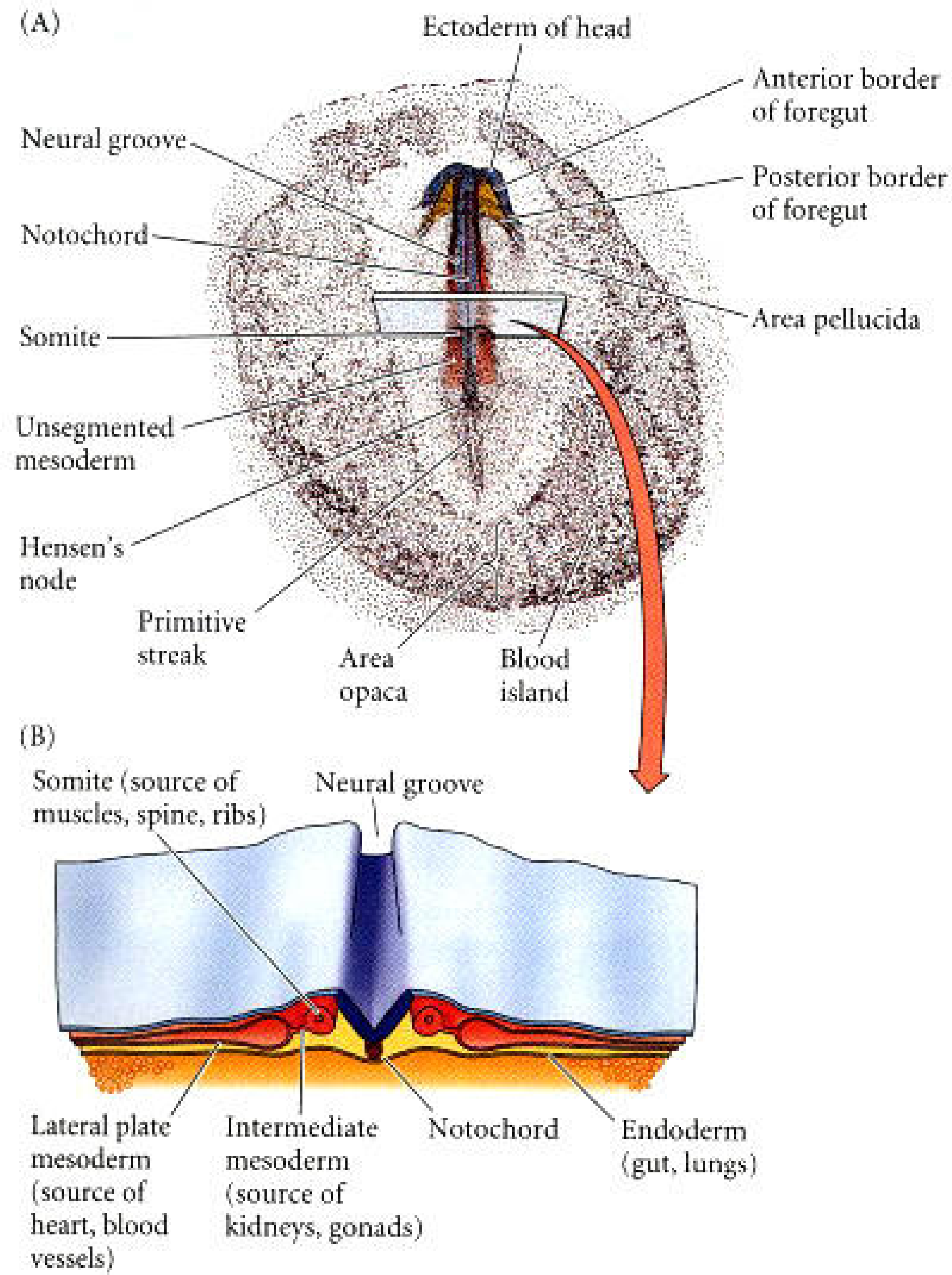
Induction

- Spemann and Mangold
  - New body axis induced by dorsal lip of blastopore
  - Spemann Organizer
  - Organs are constructed from simpler structures that interact, therefore preformation cannot occur



Notochord

- Directs the development of nervous system in vertebrates.



Genetics and Embryology

DNA contains genes that code for proteins that control development.

Change gene > change protein > alter development

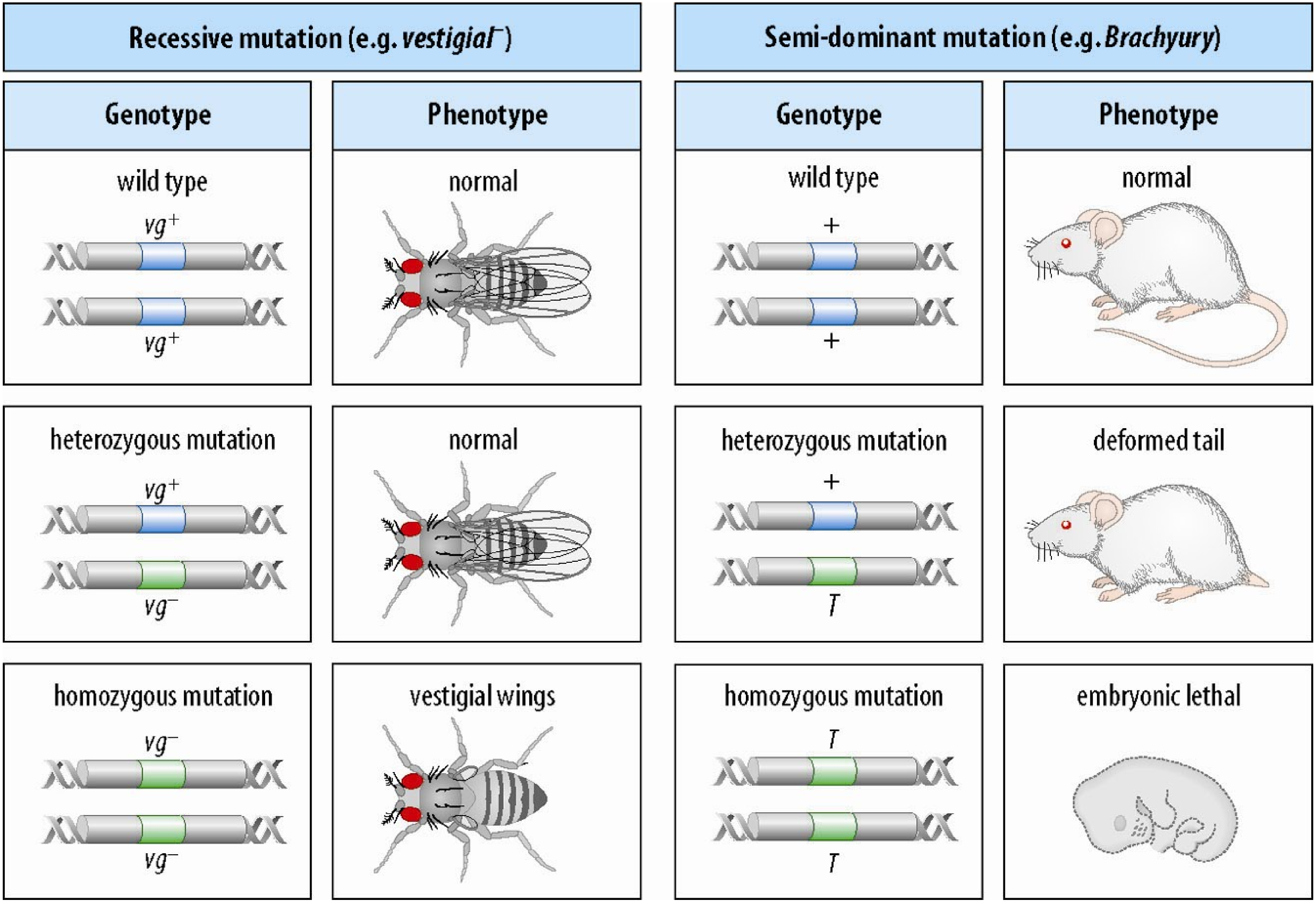

Recessive mutation (e.g. vestigial⁻)
Genotype
Phenotype
wild type
vg+
vg+
normal
heterozygous mutation
vg+
vg−
normal
homozygous mutation
vg−
vg−
vestigial wings
Semi-dominant mutation (e.g. Brachyury)
Genotype
Phenotype
wild type
+
+
normal
heterozygous mutation
+
T
deformed tail
homozygous mutation
T
T
embryonic lethal

Fig. 1.12

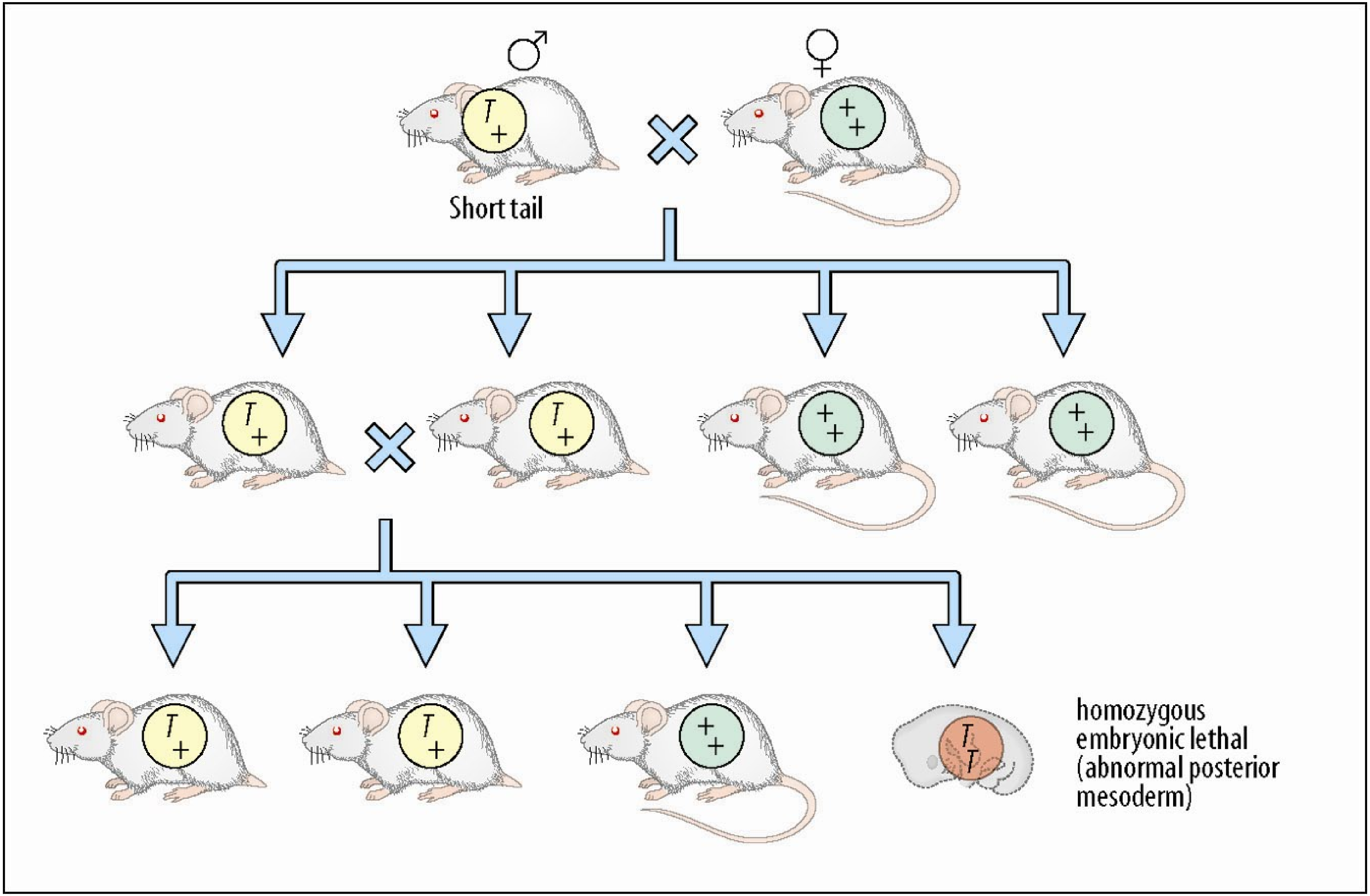

♂
♀
T
+
+
+
Short tail
T
+
T
+
+
+
+
+
T
+
T
+
+
+
T
T
homozygous
embryonic lethal
(abnormal posterior
mesoderm)

Fig. 1.13

Genetic Tools

- Lethal mutations
  - Semi-dominant
  - Recessive
- Conditional mutations
  - Temperature sensitive mutations
- Gene knock-out
- Gene silencing (gene knockdown)

Cleavage

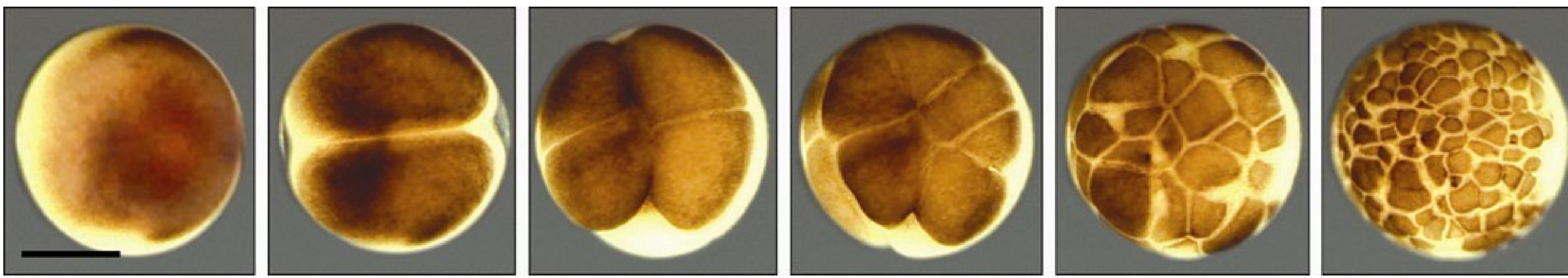


Fig. 1.14

Fundamental Developmental Processes

- Pattern formation – overall body plan
  - Polarity
  - Antero-posterior axis
  - Dorso-ventral axis
  - Segmentation
- Morphogenesis – movement of cells and tissues
  - Gastrulation
  - Neurulation
- Cell differentiation – change in cell structure and function
- Growth – increase in size

Pattern Formation

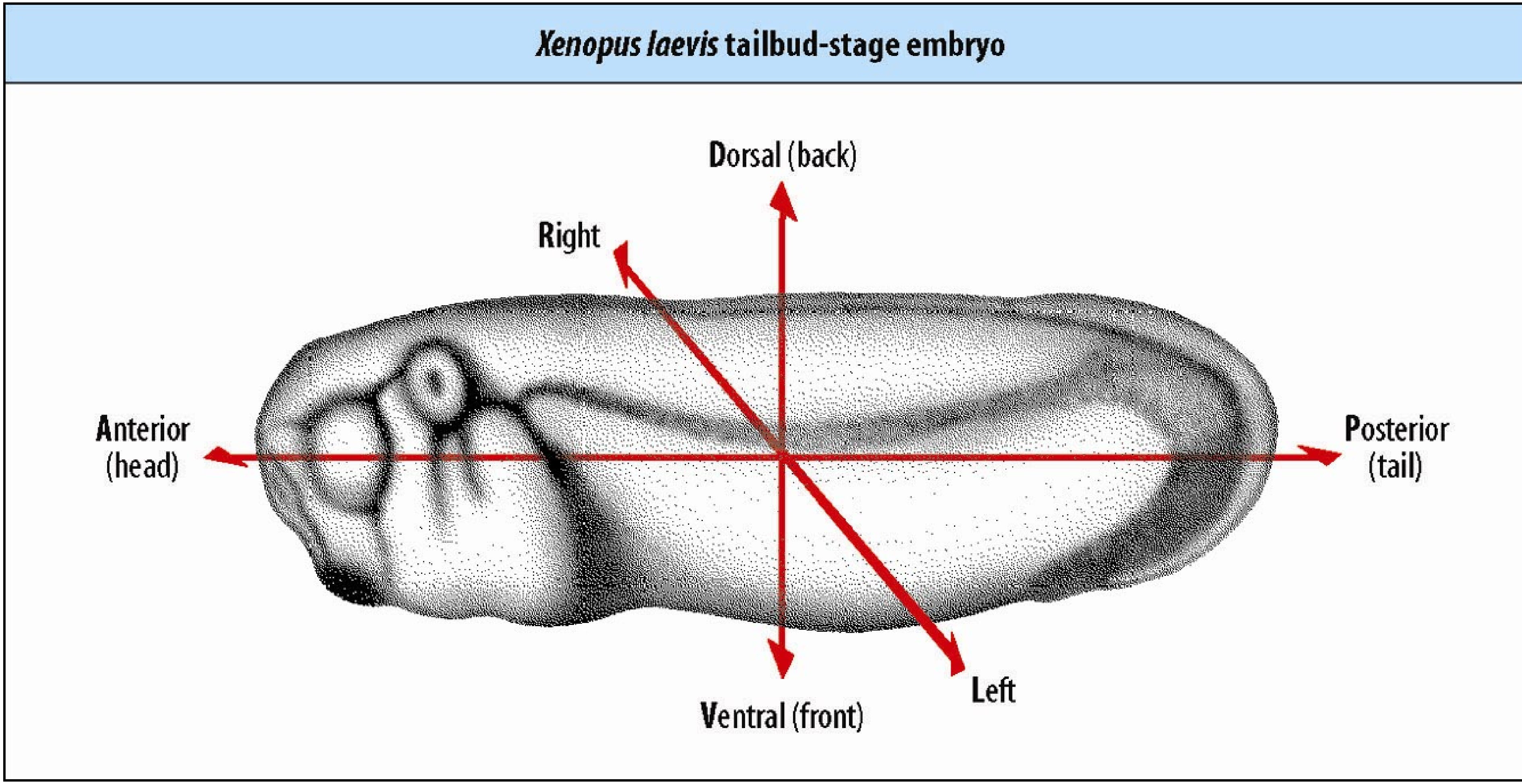


Fig. 1.15

Morphogenesis

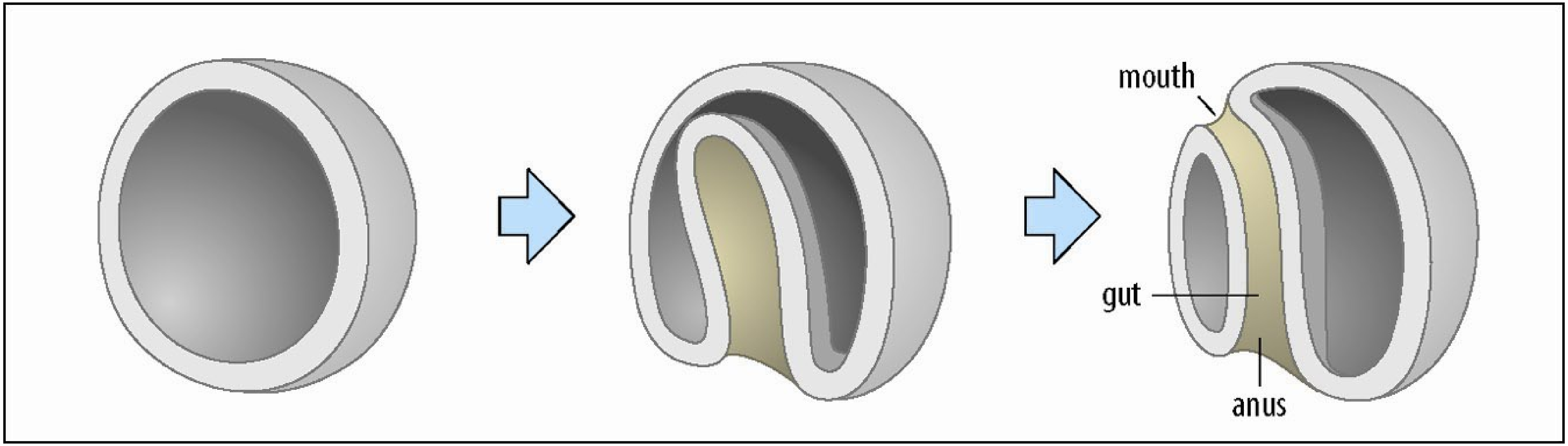


Fig. 1.16

Growth

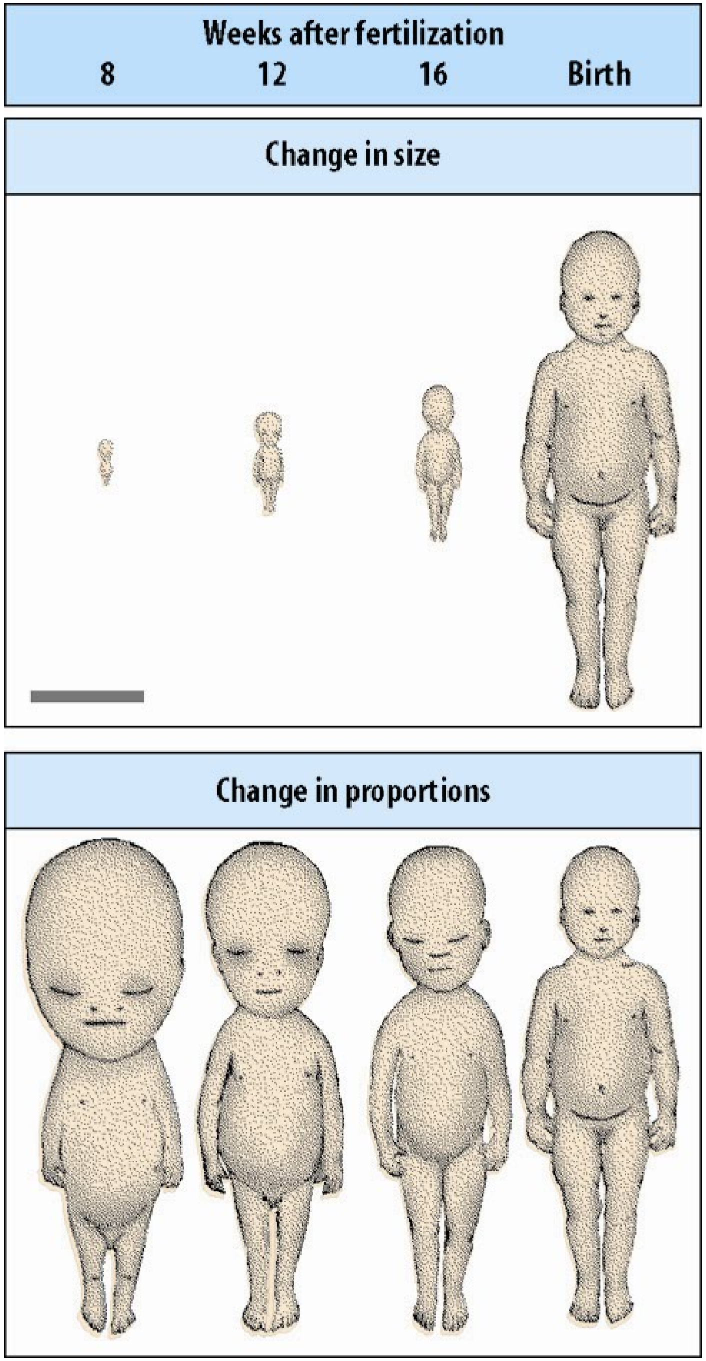
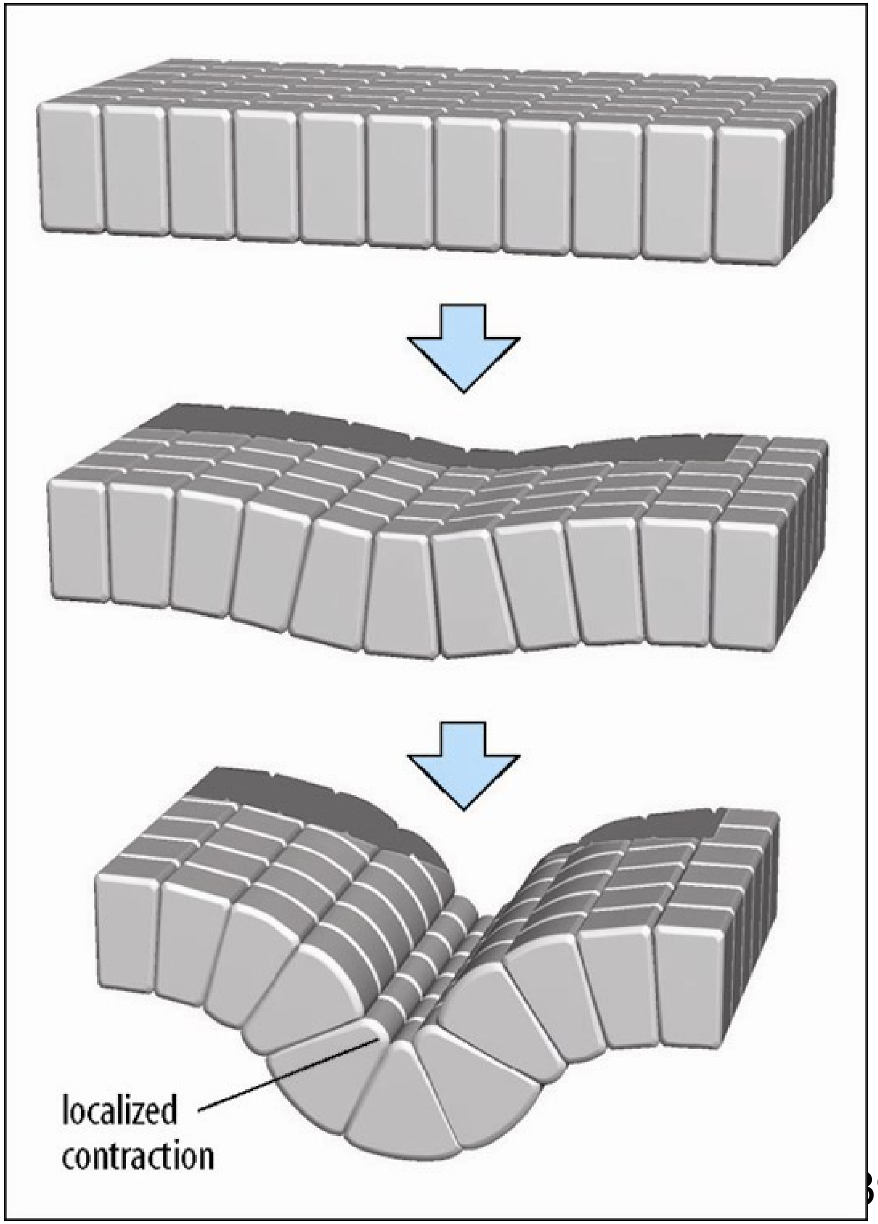


Fig. 1.17

Proteins Control Development

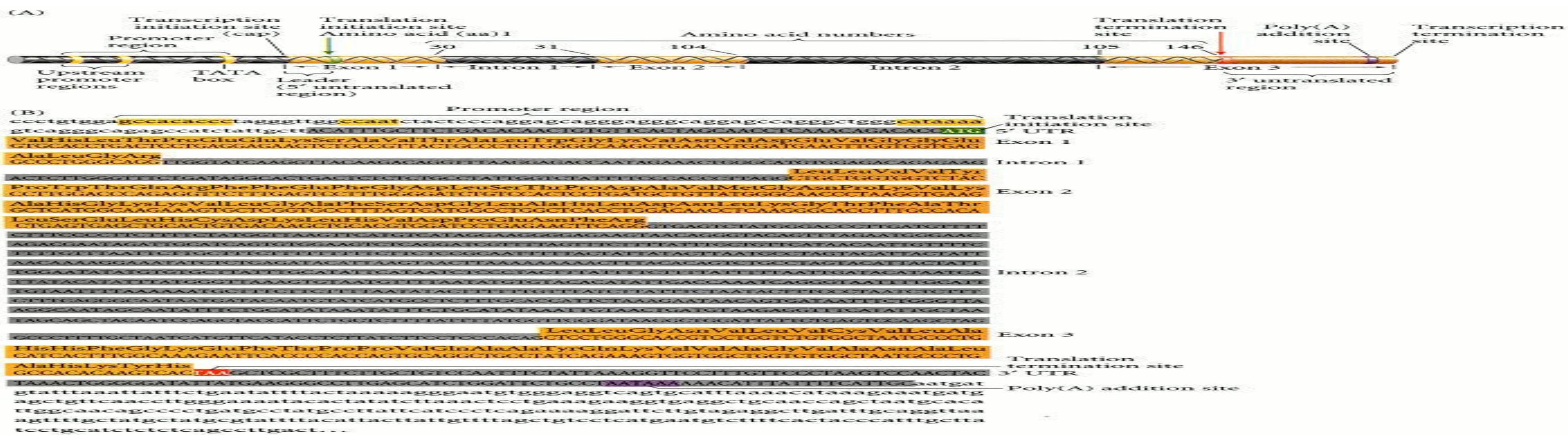
Fig. 1.18

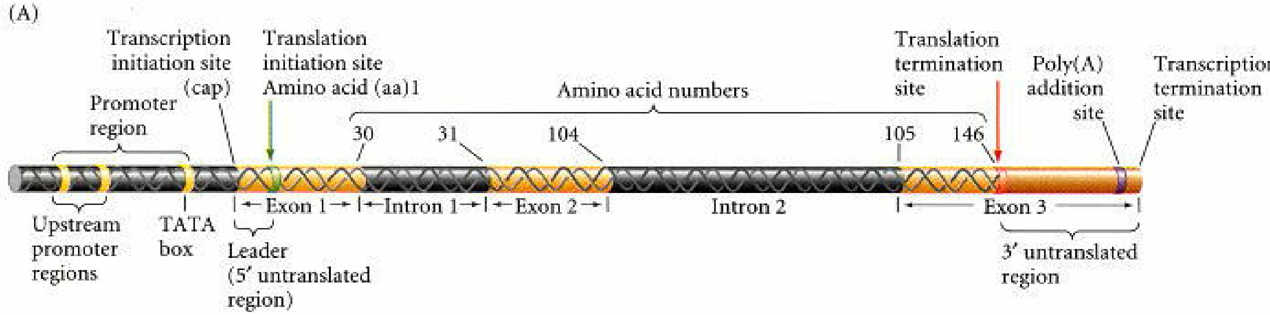


Protein Functions

- Cell signaling
  - Cell adhesion proteins
  - Diffusable signals
  - Receptors
- Gene expression
  - Transcription factors
  - DNA methylation
- Cell cycle proteins
- Structural
  - Cytoskeletal components
  - Extracellular matrix
- Enzymes

Human betaglobin gene

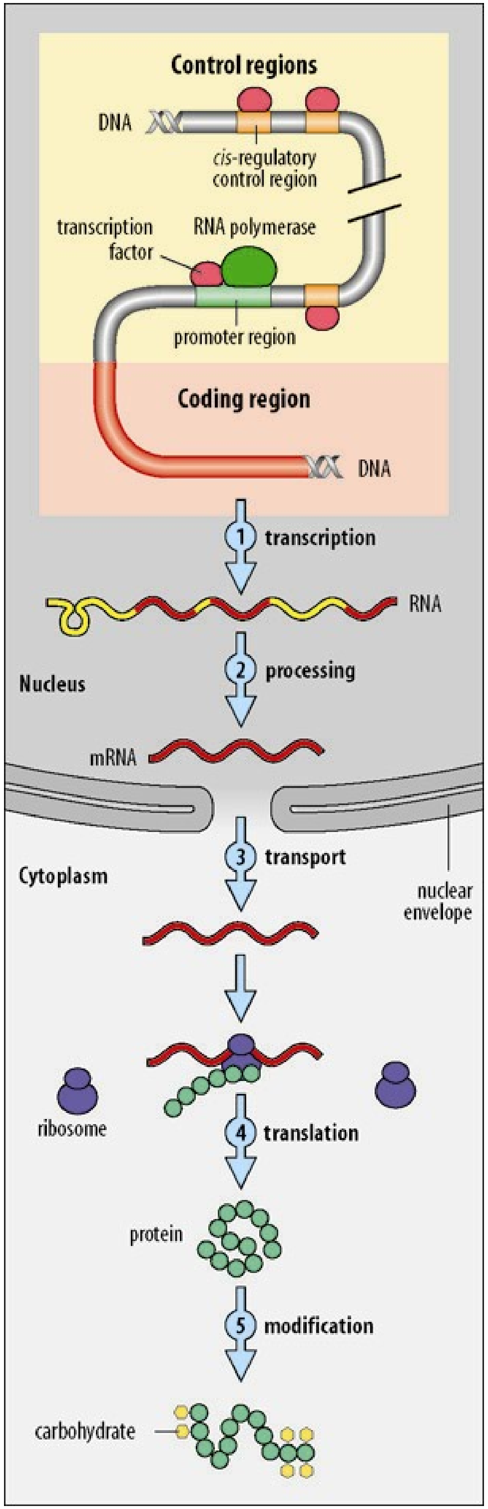



(A)
Transcription initiation site (cap)
Translation initiation site Amino acid (aa)1
Promoter region
Amino acid numbers
30
31
104
105
146
Translation termination site
Poly(A) addition site
Transcription termination site
Exon 1
Intron 1
Exon 2
Intron 2
Exon 3
Upstream promoter regions
TATA box
Leader (5′ untranslated region)
3′ untranslated region


(B)
Promoter region
Translation initiation site
5′ UTR
ValHisLeuThrProGluGluLysSerAlaValThrAlaLeuTrpGlyLysValAsnValAspGluValGlyGlyGlu
Exon 1
AlaLeuGlyArg
Intron 1
LeuLeuValValTyr
ProTrpThrGlnArgPhePheGluPheGlyAspLeuSerThrProAspAlaValMetGlyAsnProLysValLys
Exon 2
AlaHisGlyLysLysValLeuGlyAlaPheSerAspGlyLeuAlaHisLeuAspAsnLeuLysGlyThrPheAlaThr
LeuSerGluLeuHisCysAspLysLeuHisValAspProGluAsnPheArg
Intron 2
LeuLeuGlyAsnValLeuValCysValLeuAla
Exon 3
HisHisPheGlyLysGluPheThrProProValGlnAlaAlaTyrGlnLysValValAlaGlyValAlaAsnAlaLeu
AlaHisLysTyrHis
Translation termination site
3′ UTR
Poly(A) addition site

Protein Synthesis

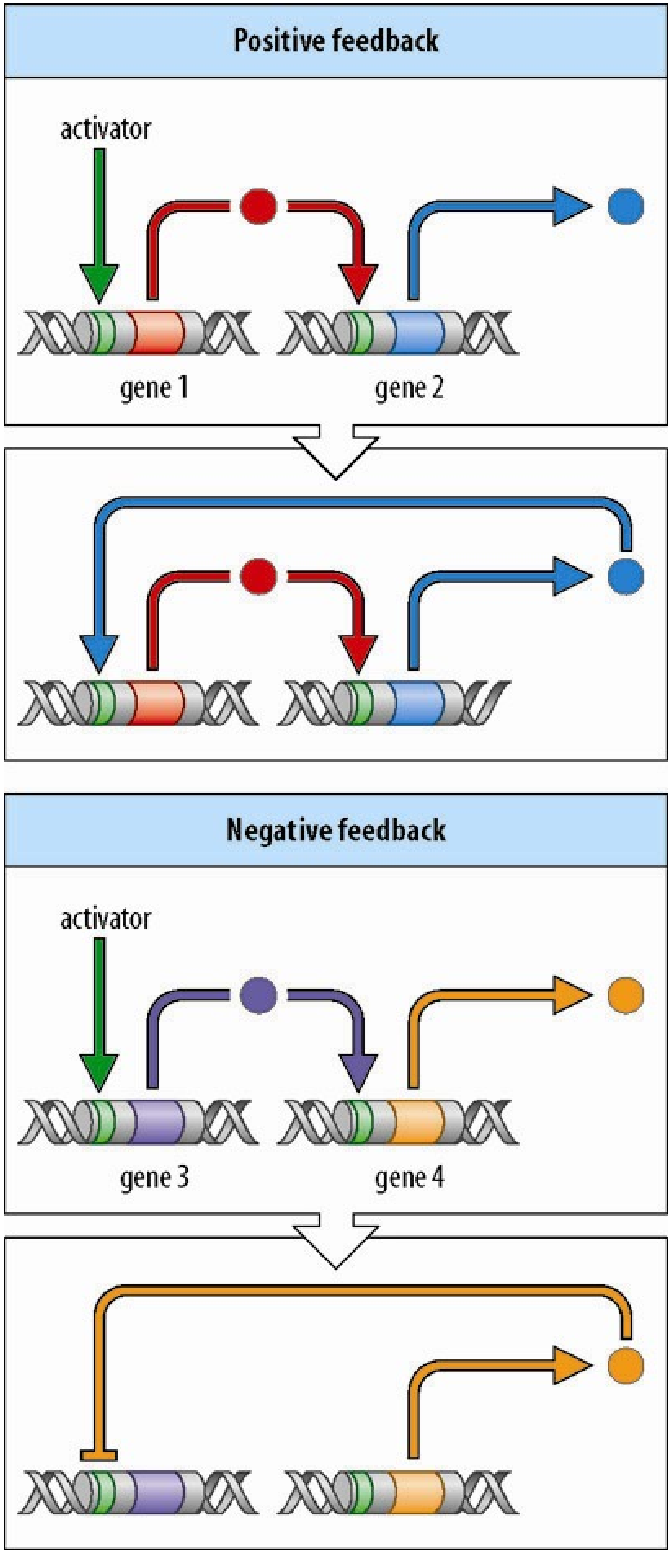
Control of gene expression can occur at any point during protein synthesis.

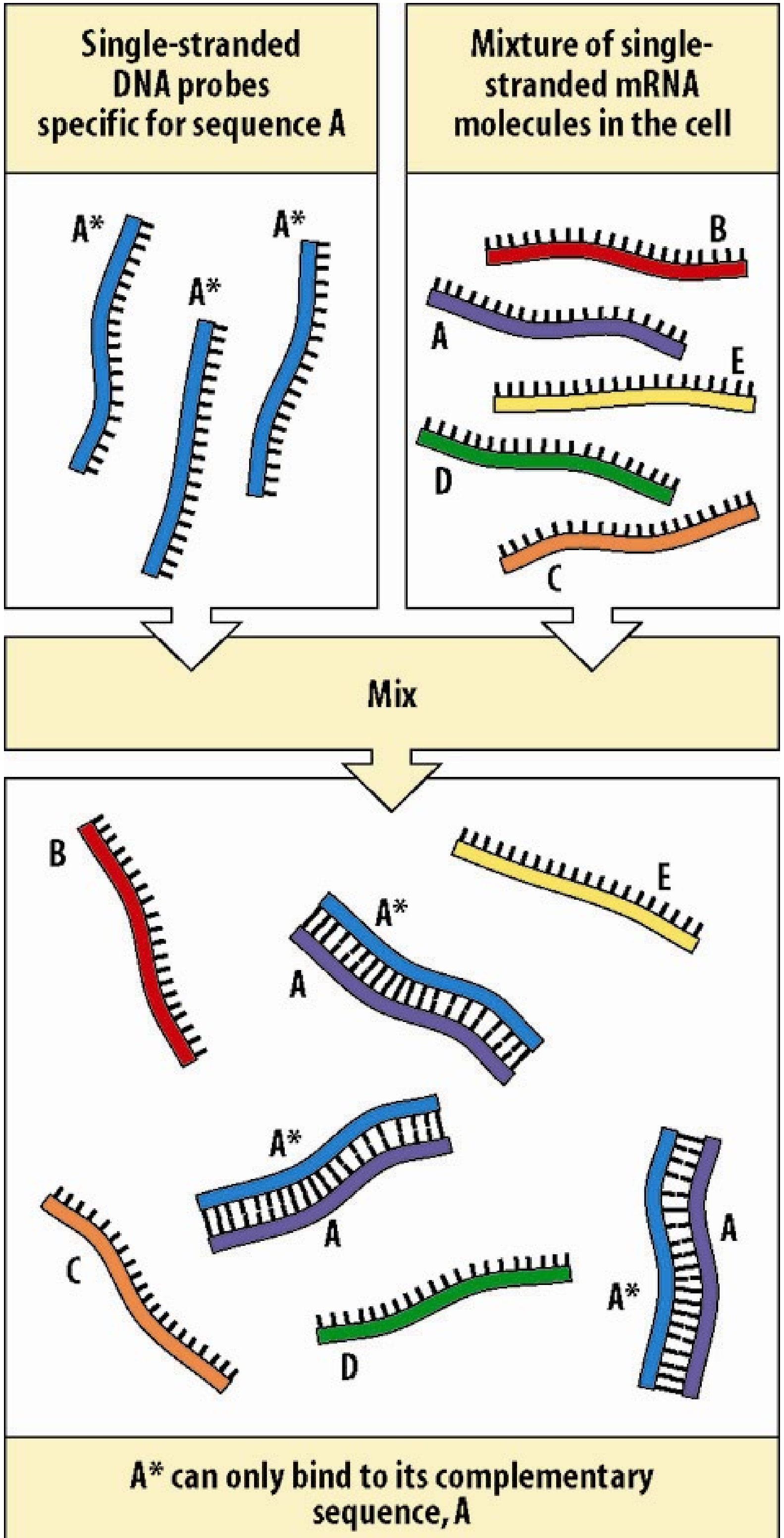


Transcriptional Control

Positive feedback – amplifies signal

Negative feedback – control strength of signal



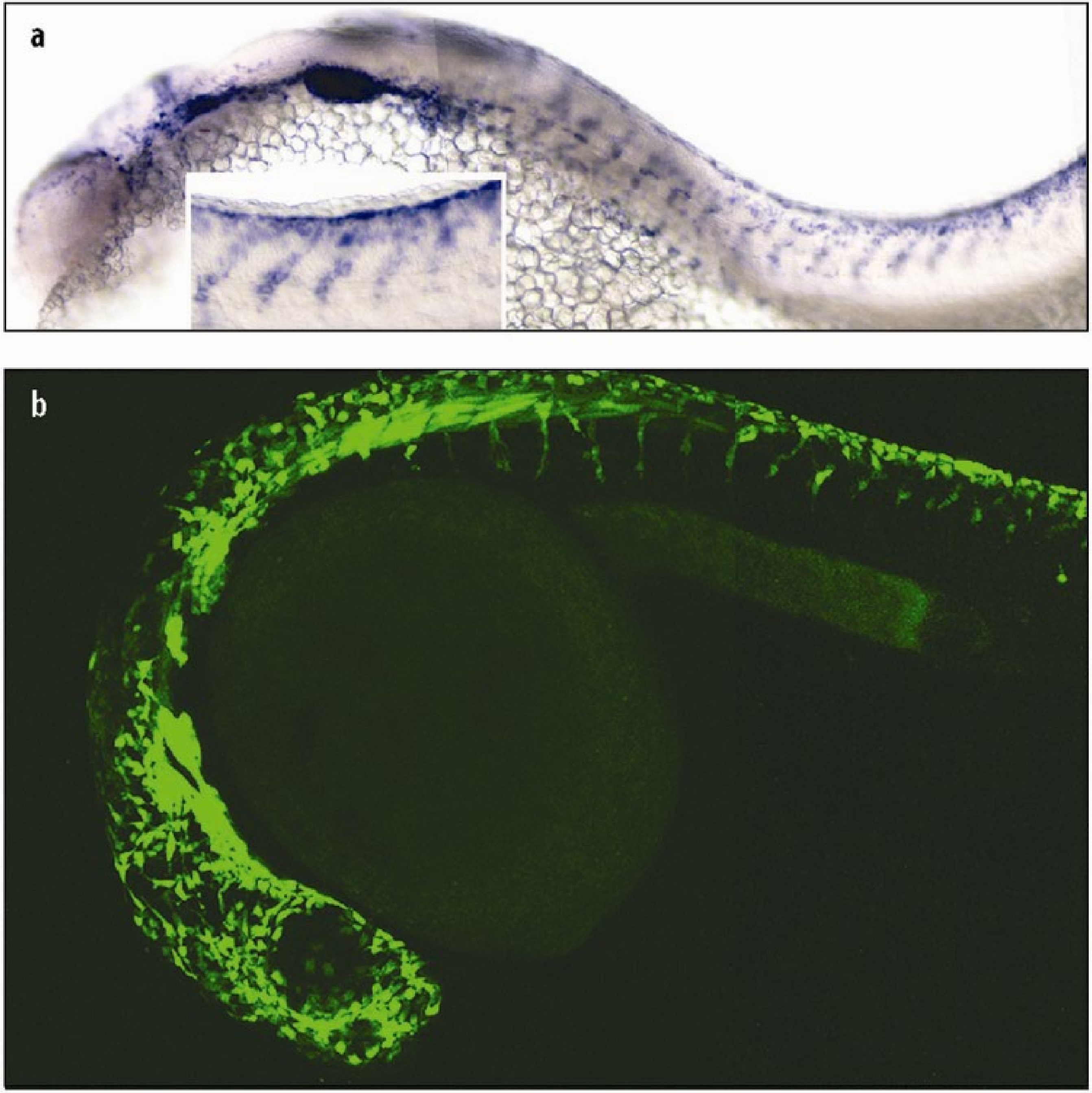


In situ Hybridization

Detects gene expression by visualizing the presence of specific mRNA.

Probes can be radioactive, fluorescent or enzymatic.

Box 1D2



Use of Reporter Genes in Development

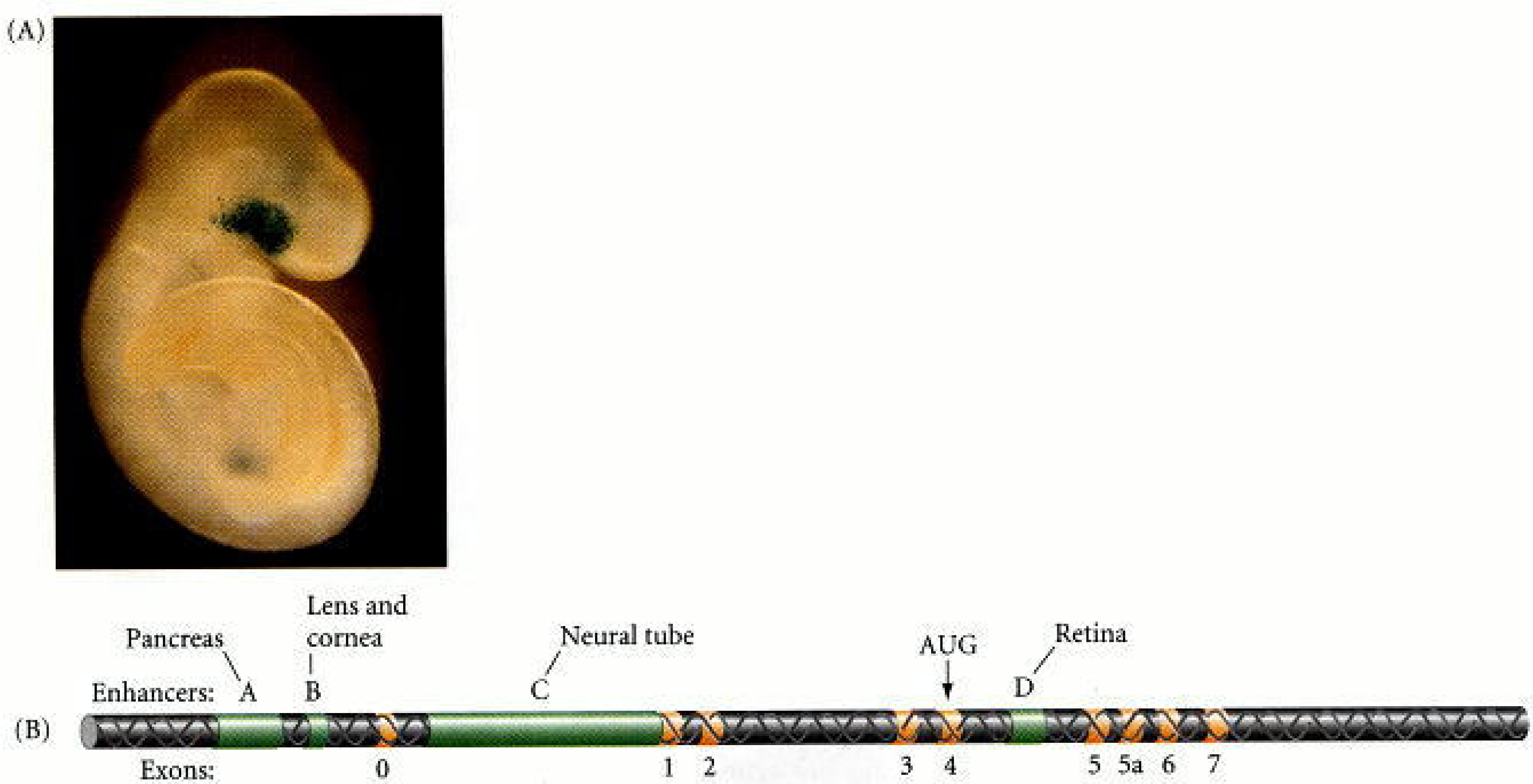
LacZ gene

- Codes for betagalactosidase protein
- Stains tissue dark blue

GFP gene

- Codes for green fluorescent protein
- Fluoresces green

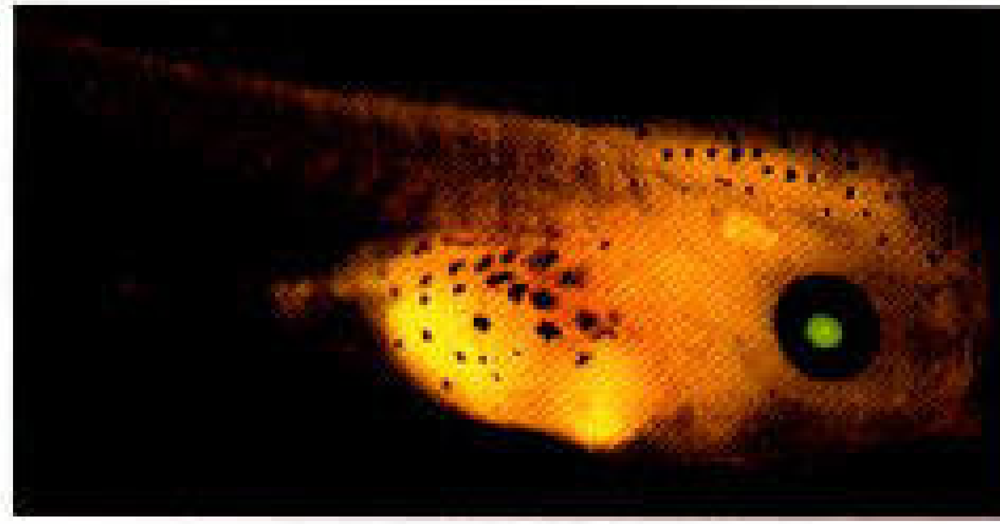
Pax6 gene betagalactosidase staining



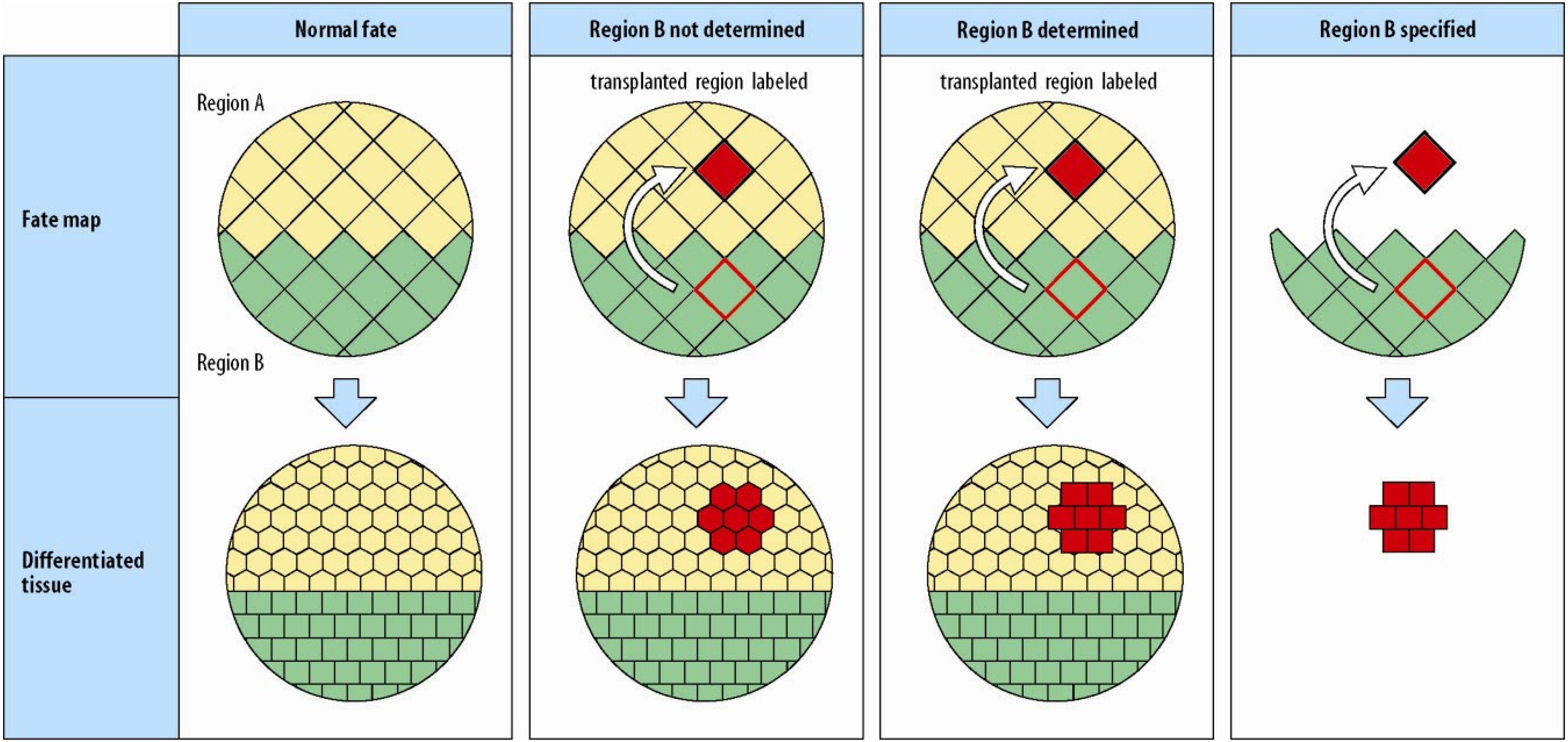
Myf-5 expression (lacZ)
-muscle devlopement

Crystallin Expression (GFP)
-lens development

(B)



Cell Fate, determination and specification



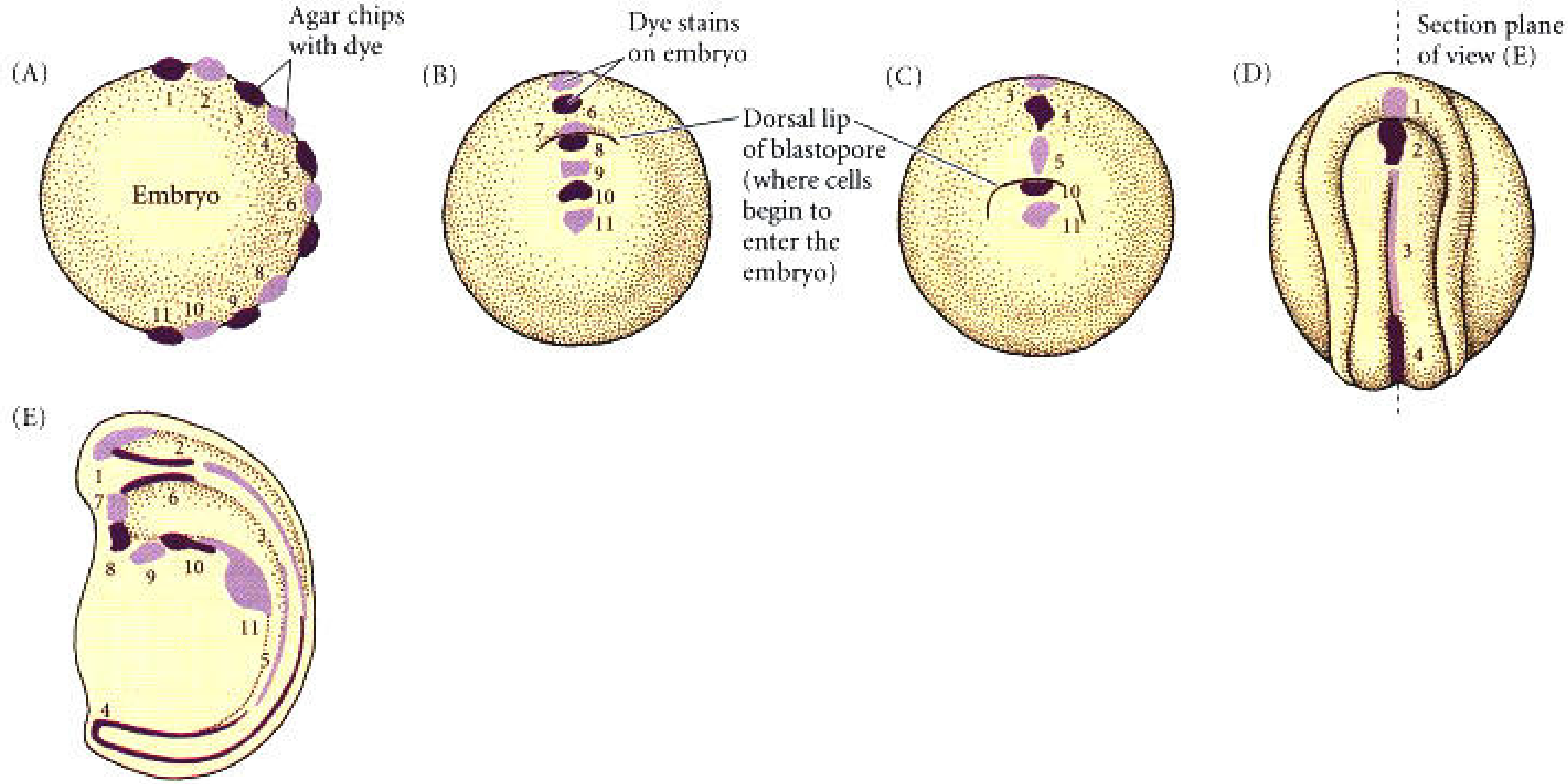
Vital Dye Staining

Developed by Vogt

Method to stain cells without killing them

Allows you to follow cell movement

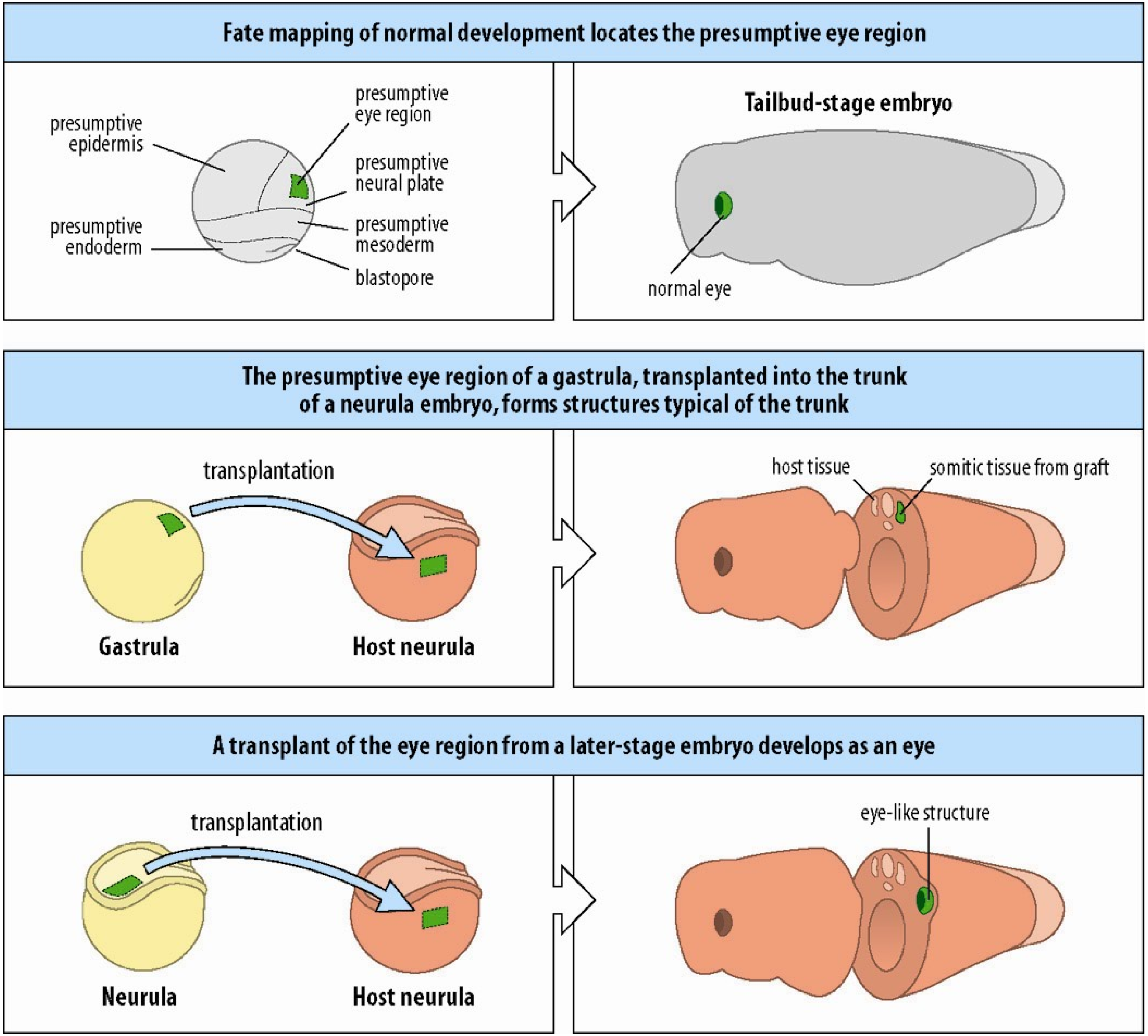
Fate mapping amphibian embryos with vital dyes



Modern Fate Mapping

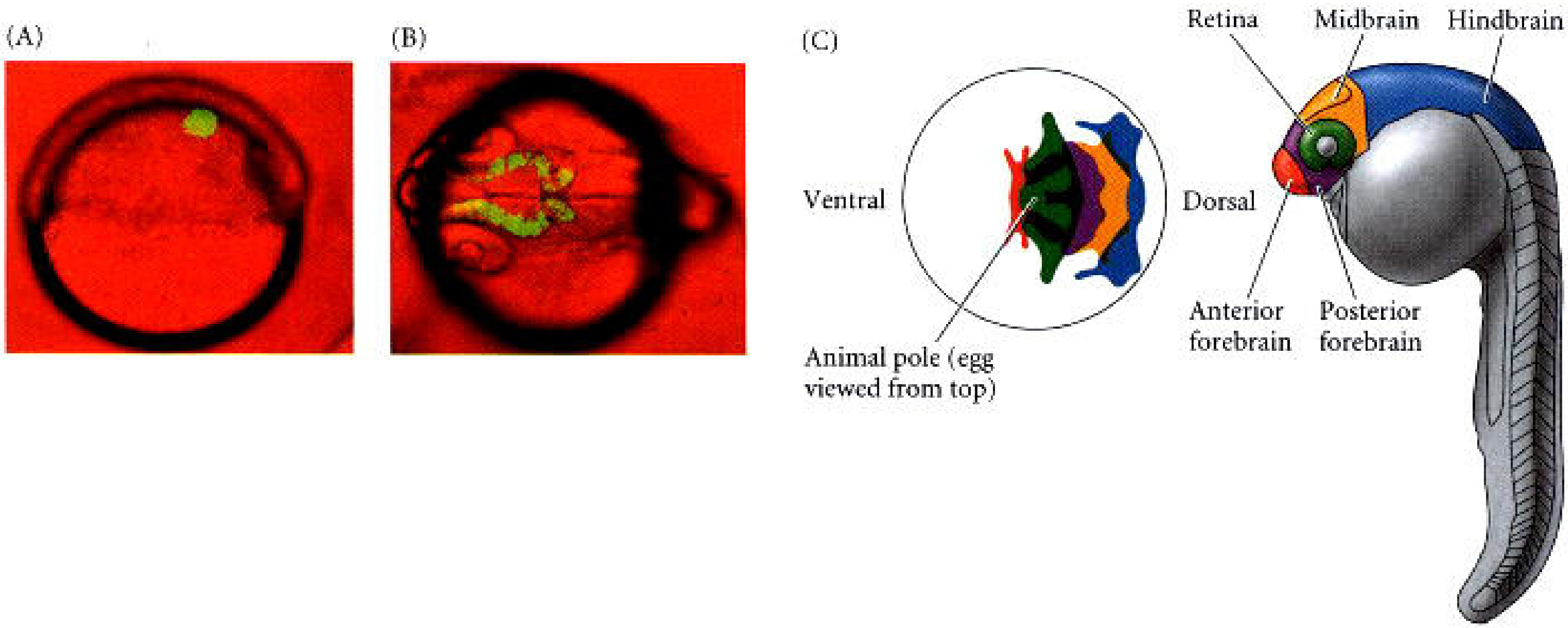
- Radioactive labeling
- Grafting
- Mosaic embryos
- Fluorescent dyes
- Antibody labels
- DNA and RNA probes

Fig. 1.22

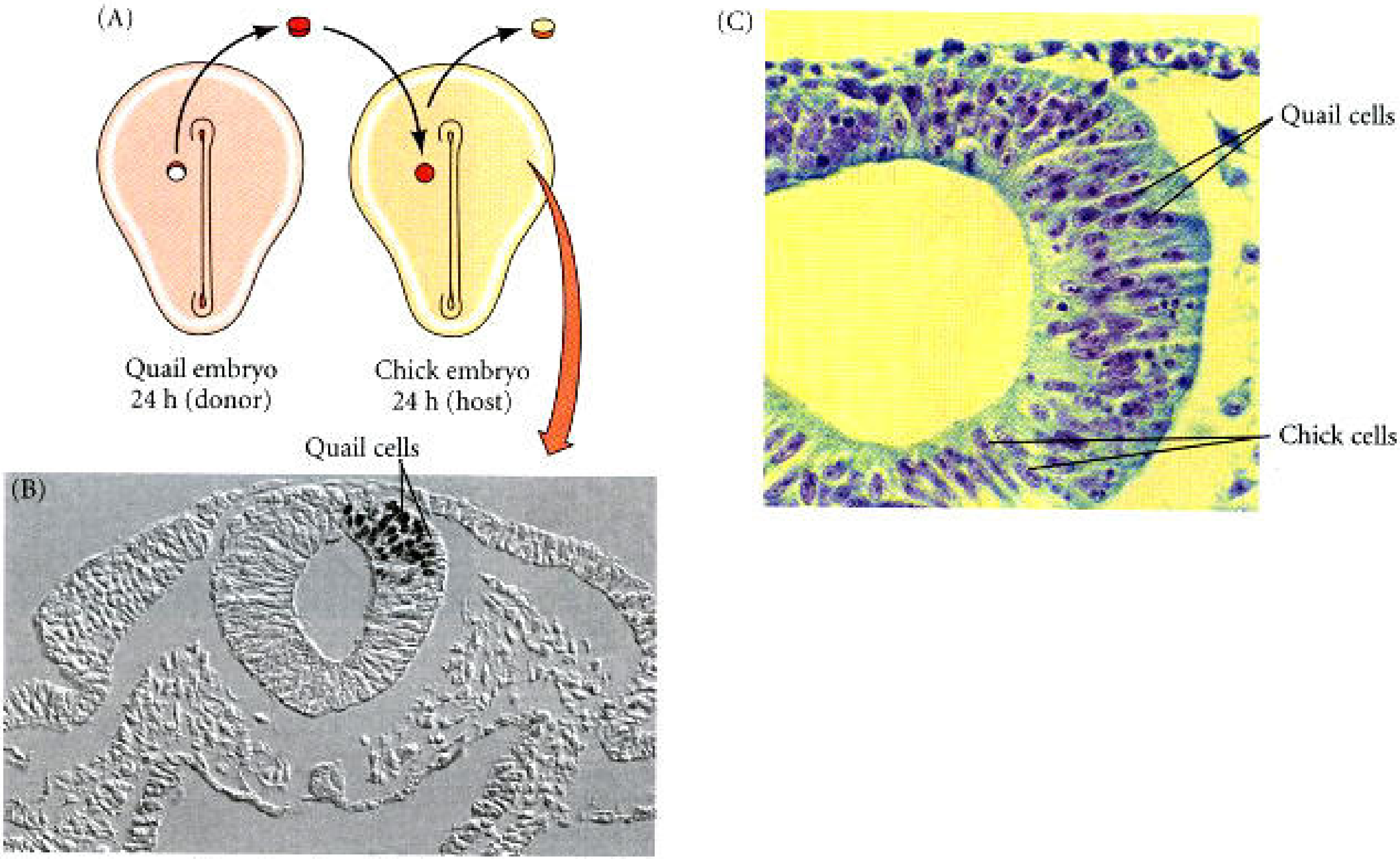


Fate mapping of normal development locates the presumptive eye region
presumptive epidermis
presumptive eye region
presumptive neural plate
presumptive mesoderm
presumptive endoderm
blastopore
Tailbud-stage embryo
normal eye
The presumptive eye region of a gastrula, transplanted into the trunk of a neurula embryo, forms structures typical of the trunk
transplantation
Gastrula
Host neurula
host tissue
somitic tissue from graft
A transplant of the eye region from a later-stage embryo develops as an eye
transplantation
Neurula
Host neurula
eye-like structure

Fate mapping with fluorescent dyes

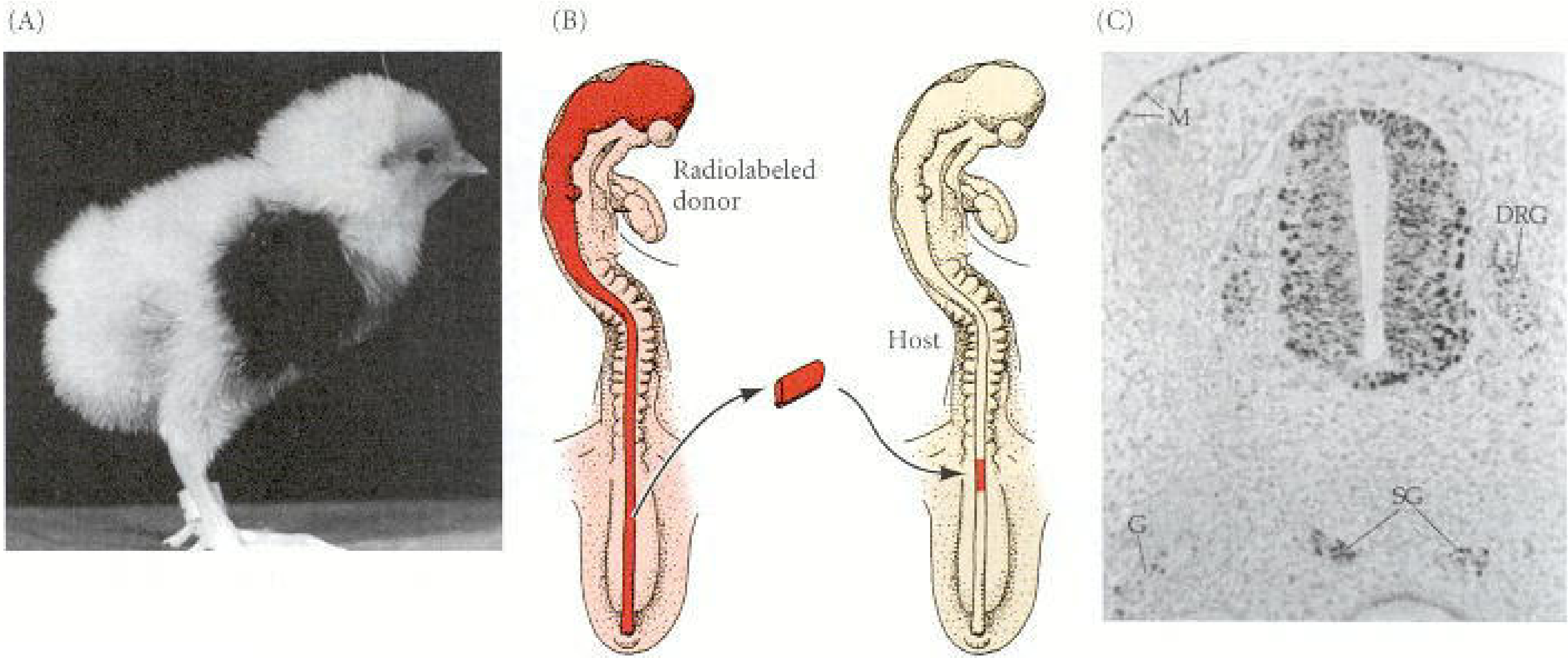


Fate mapping using grafting



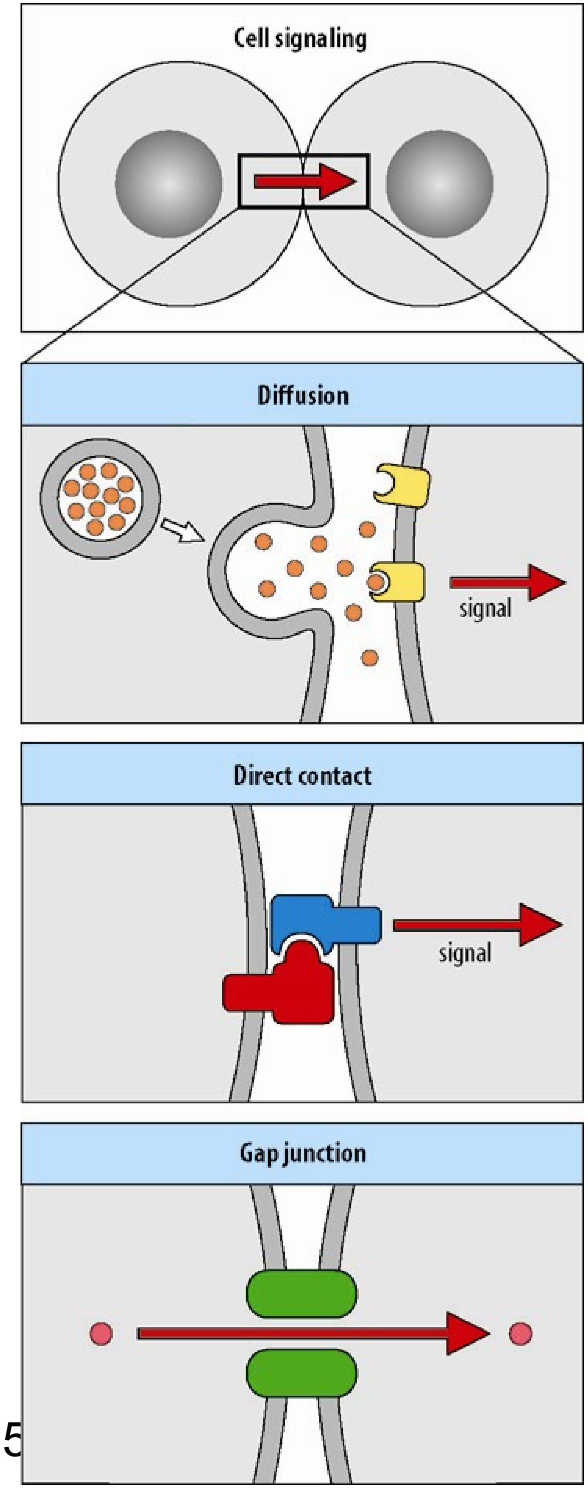
Chick embryo with region of quail cells on the neural tube

Other examples of grafting experiments



Induction

- Can be permissive or instructive
- Cell Signals
  - Diffusion
  - Direct contact
  - Gap junction
- Response to signal is dependent on factors in the receiving cell



Morphogens

- Signaling molecules
  - Threshold concentration required for activation.
  - Morphogen gradients can specify different regions of an embryo

Fig. 1.24

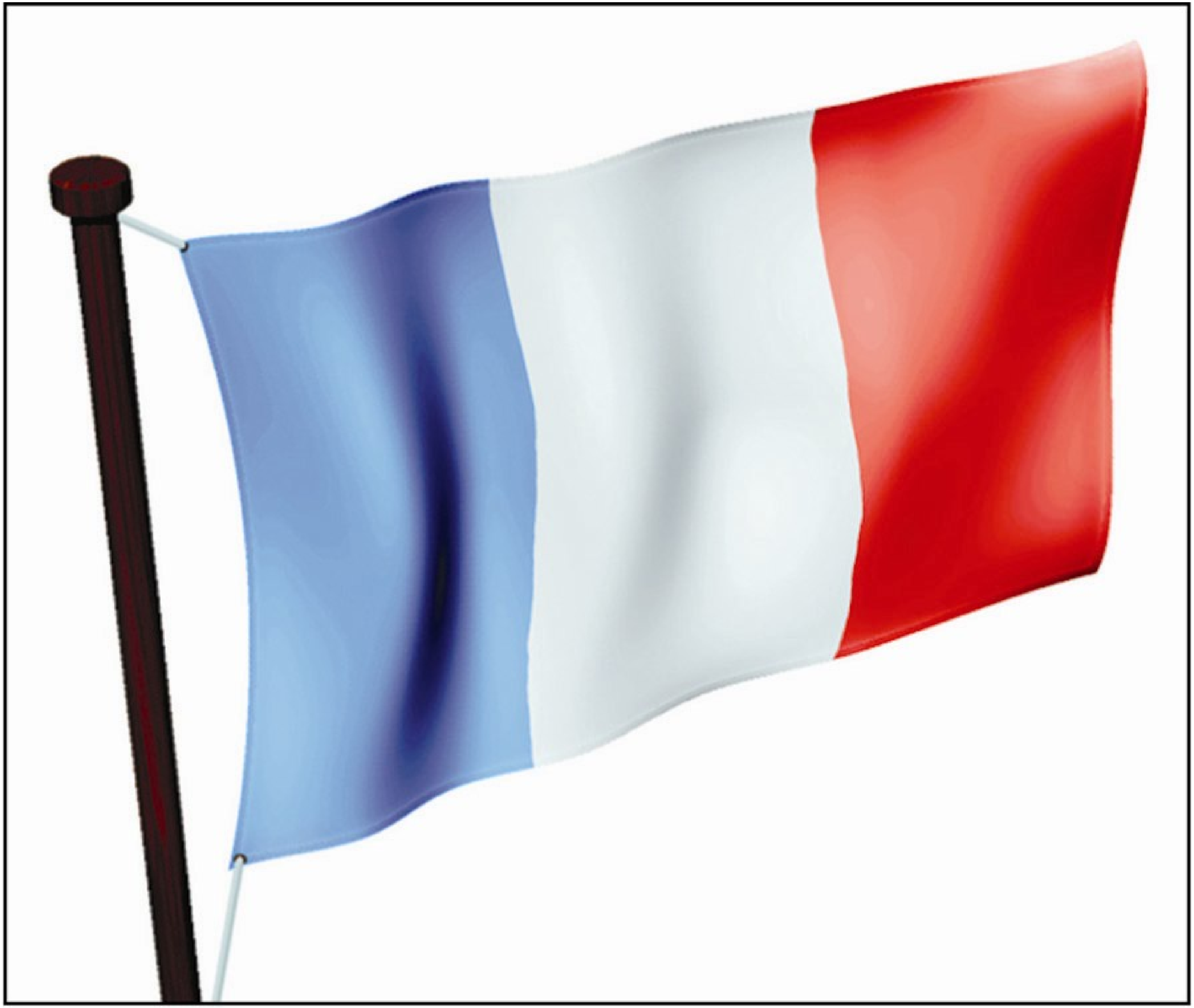
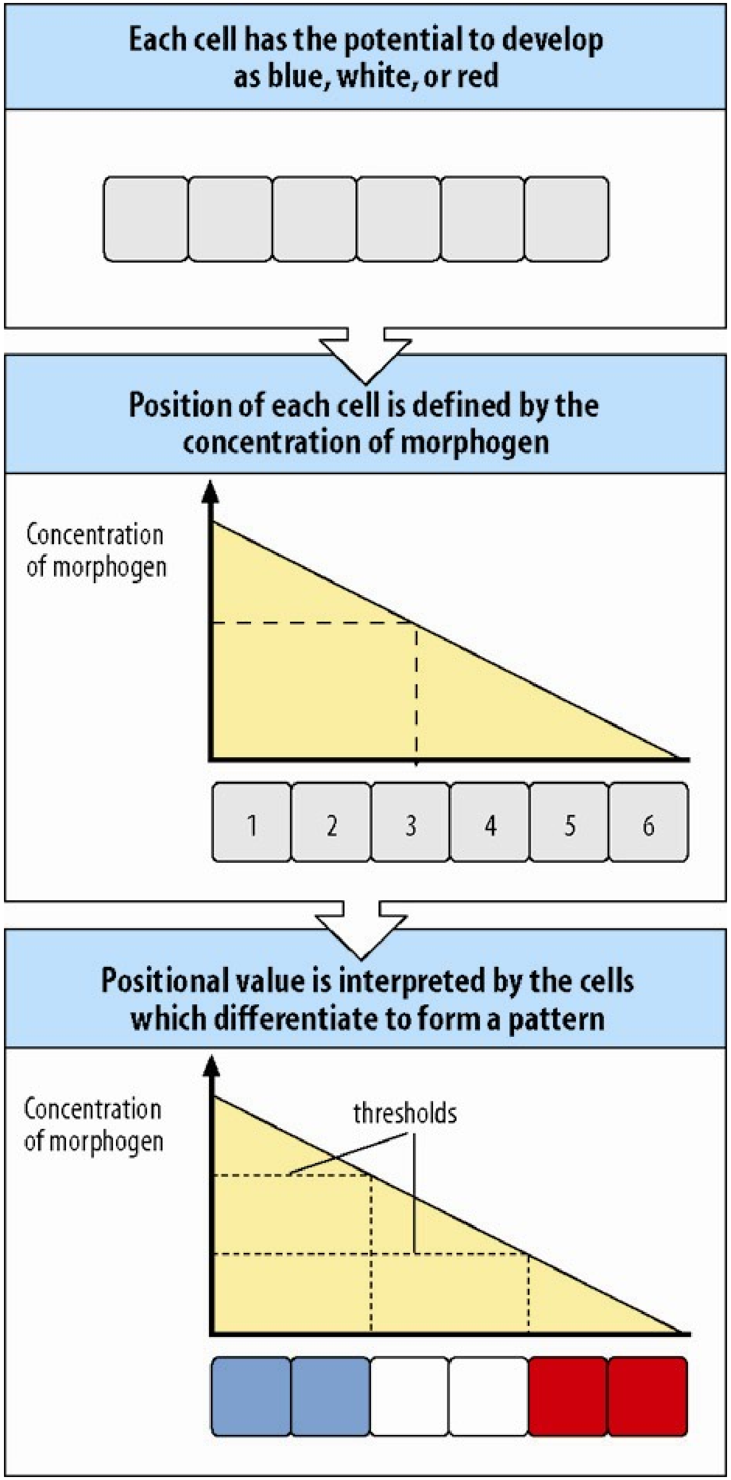


Fig. 1.25



Each cell has the potential to develop as blue, white, or red
Position of each cell is defined by the concentration of morphogen
Concentration of morphogen
1
2
3
4
5
6
Positional value is interpreted by the cells which differentiate to form a pattern
Concentration of morphogen
thresholds

Box 1E

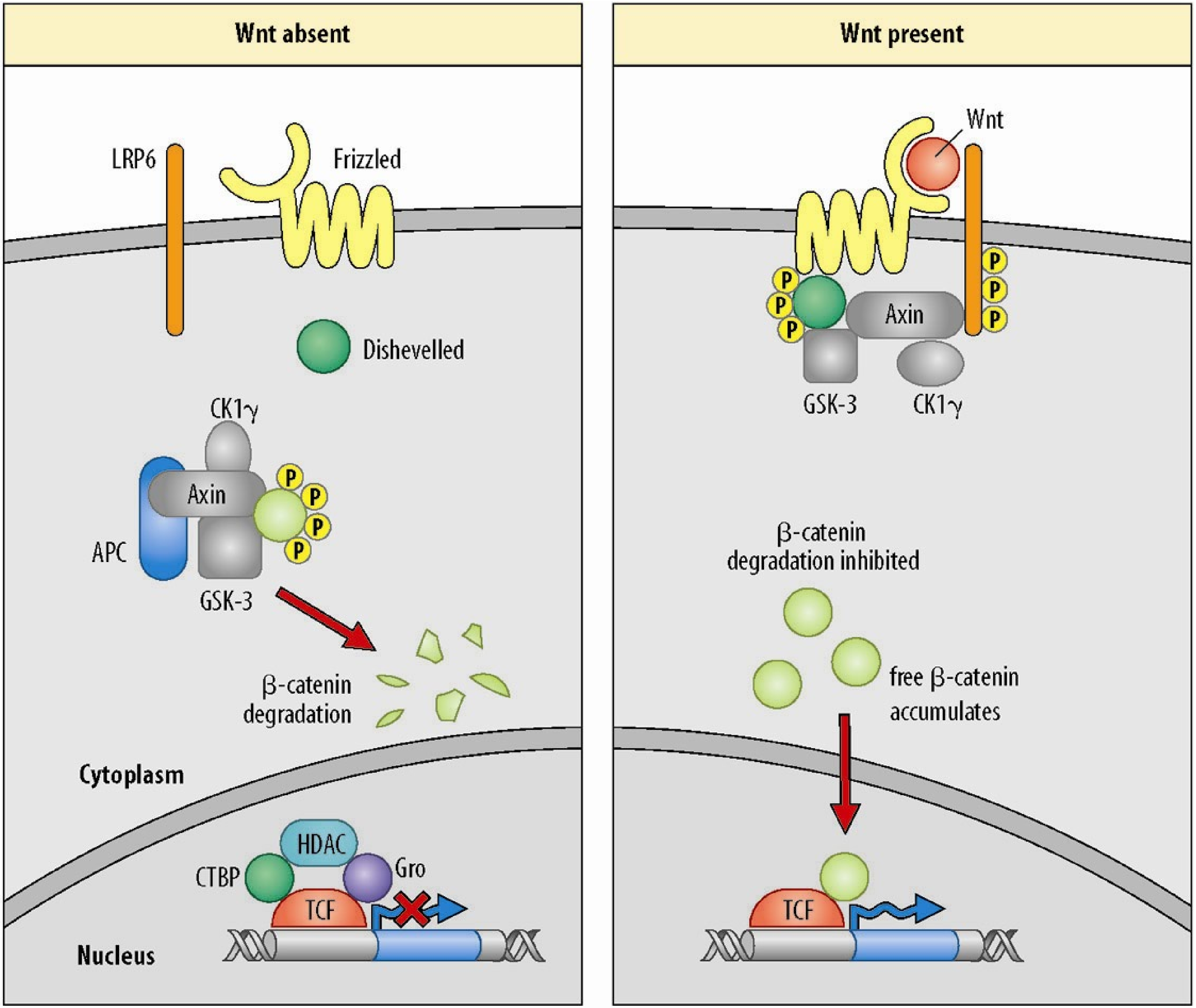
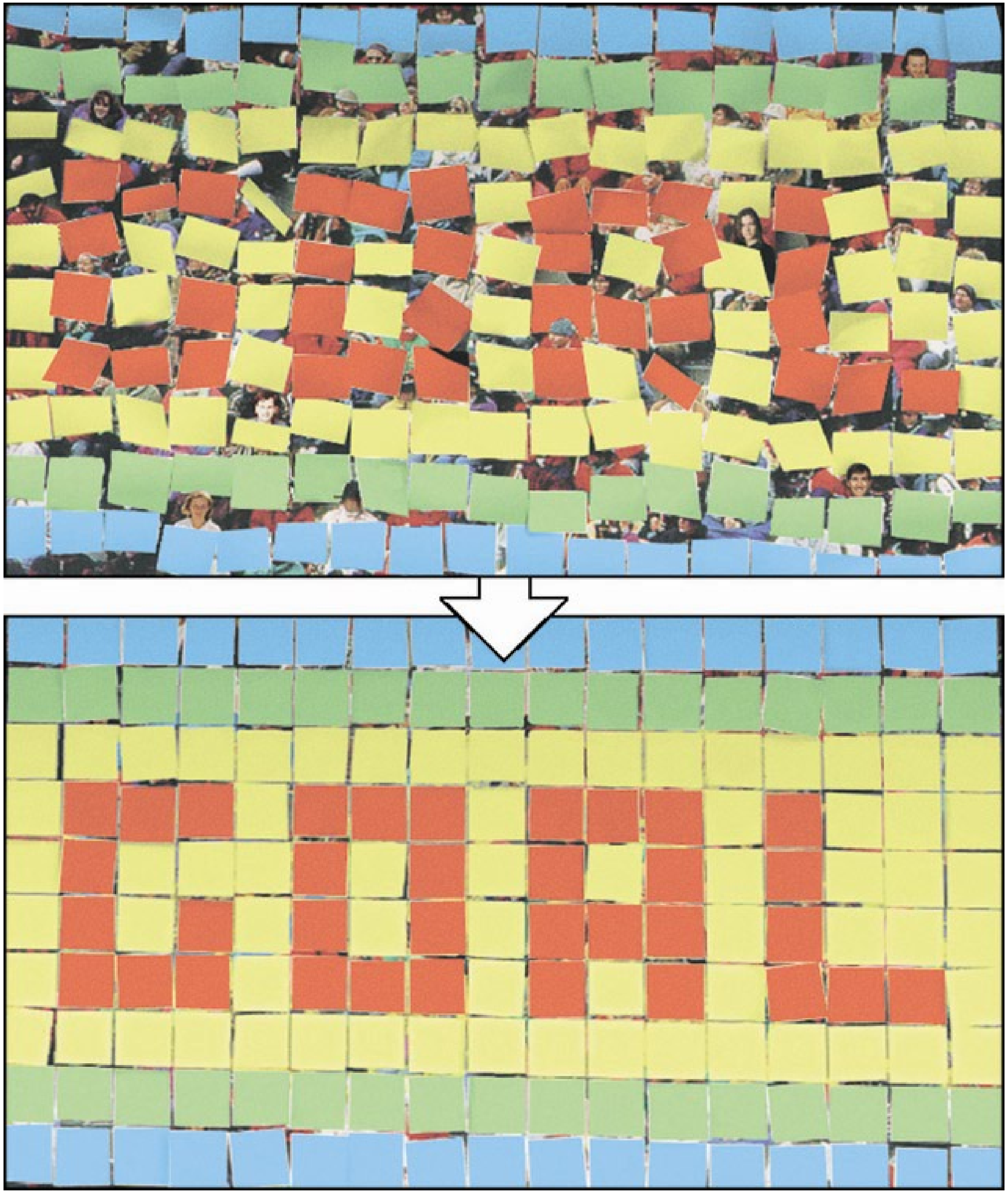
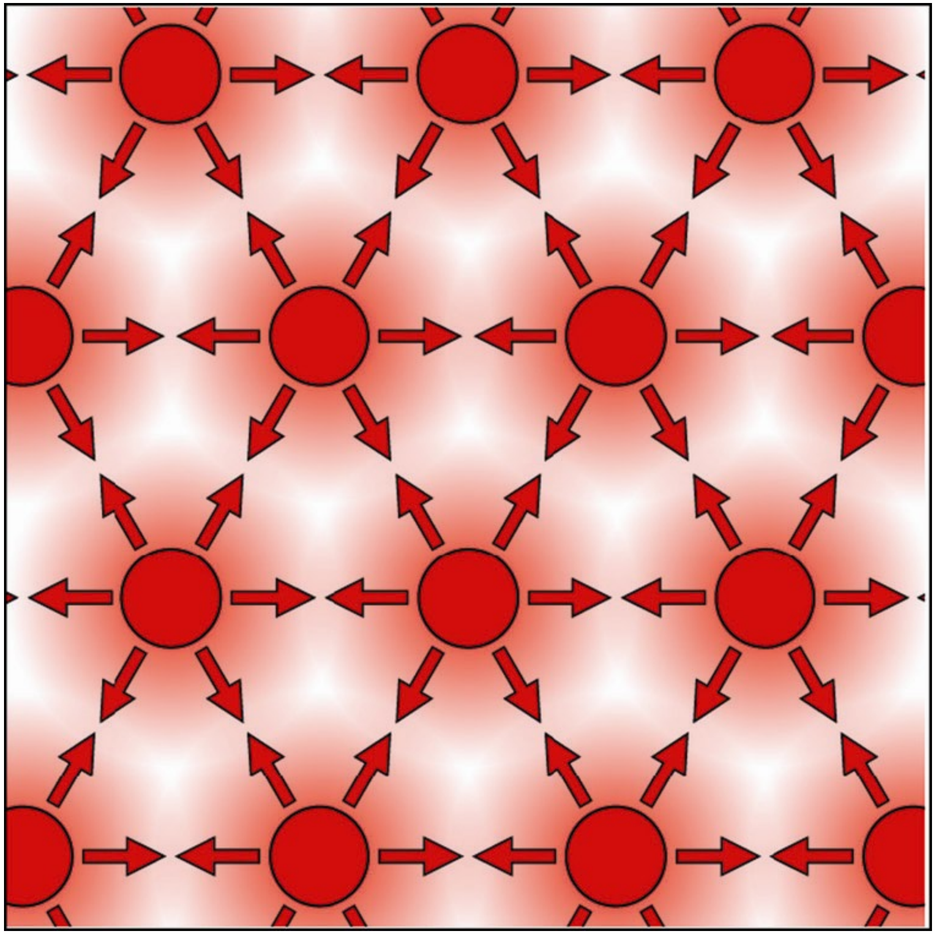

Wnt absent
LRP6
Frizzled
Dishevelled
CK1γ
Axin
P
APC
GSK-3
β-catenin
degradation
Cytoplasm
HDAC
CTBP
Gro
TCF
Nucleus
Wnt present
Wnt
P
Axin
GSK-3
CK1γ
β-catenin
degradation inhibited
free β-catenin
accumulates
TCF

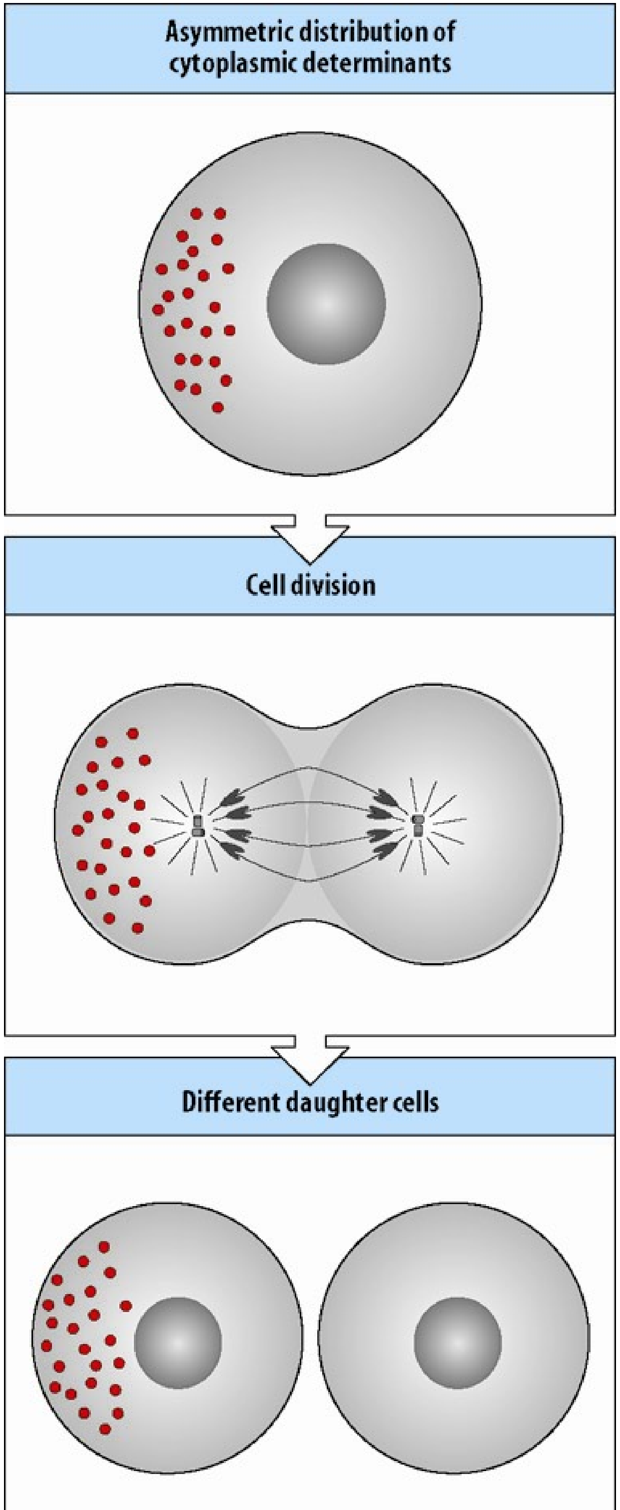
Fig. 1.26



Lateral Inhibition



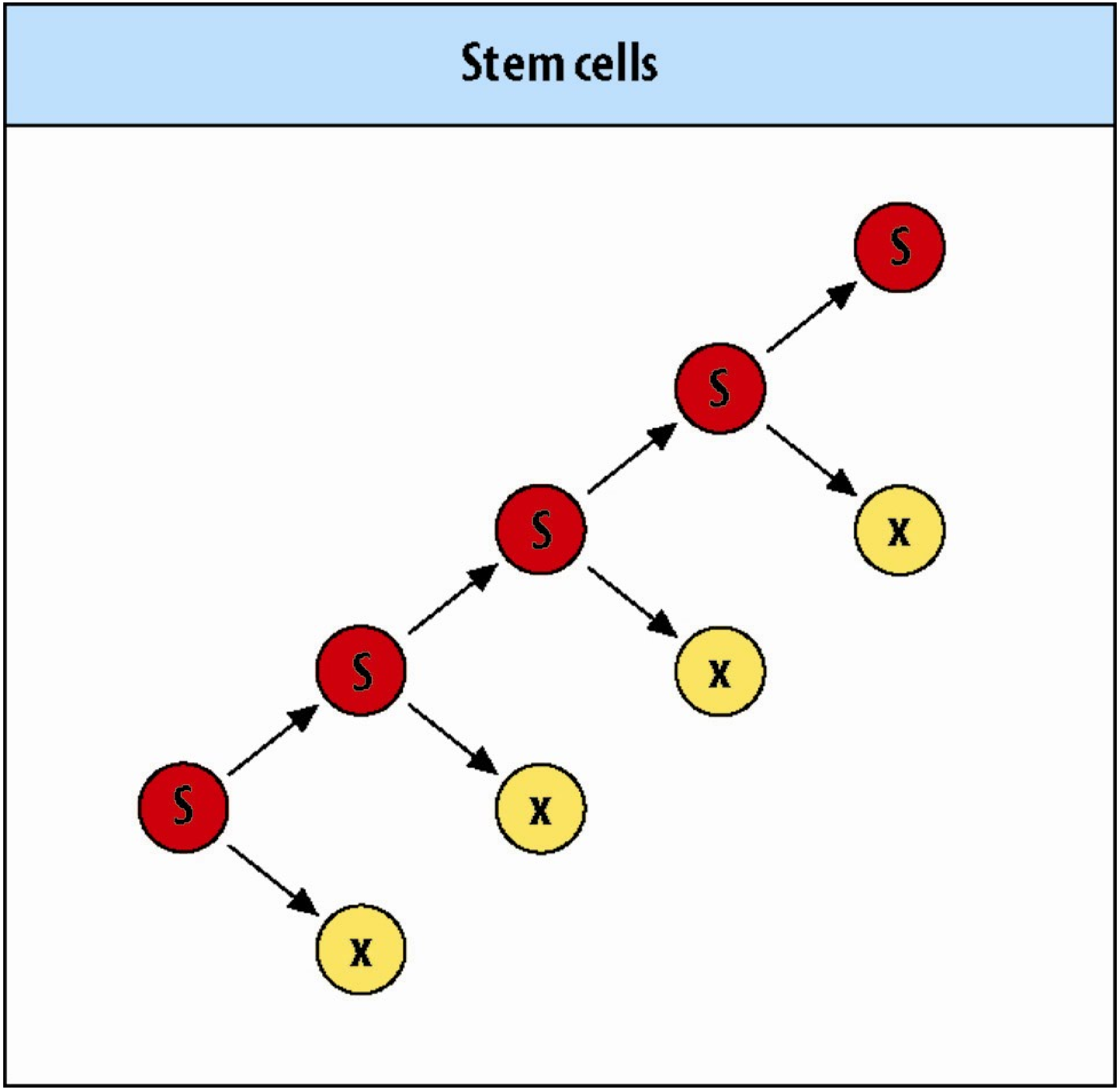
Causes evenly distributed patterns



Cytoplasmic Determinants

Asymmetrical distribution of cytoplasmic determinants produces differ cell contexts.

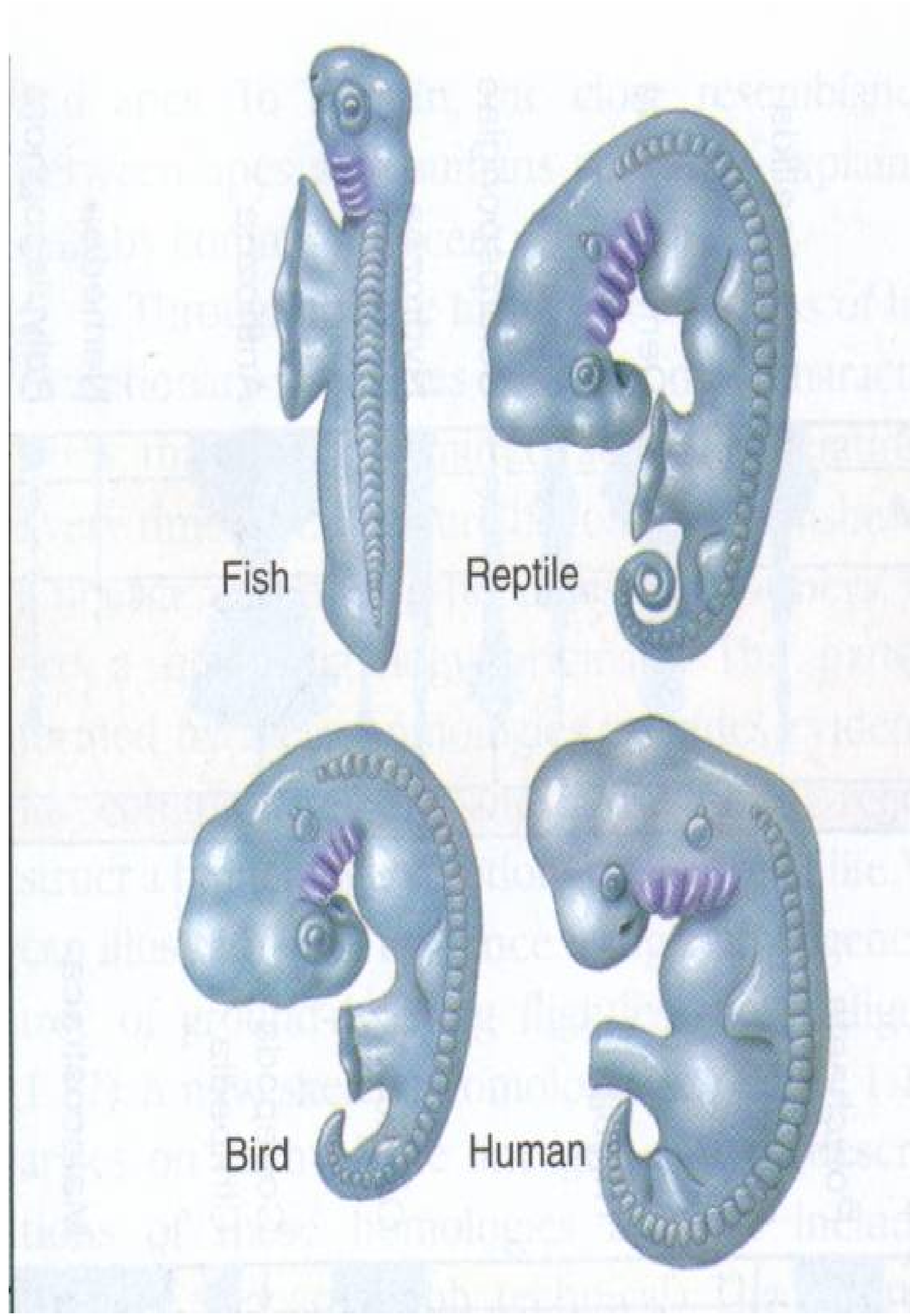
Fig. 1.29



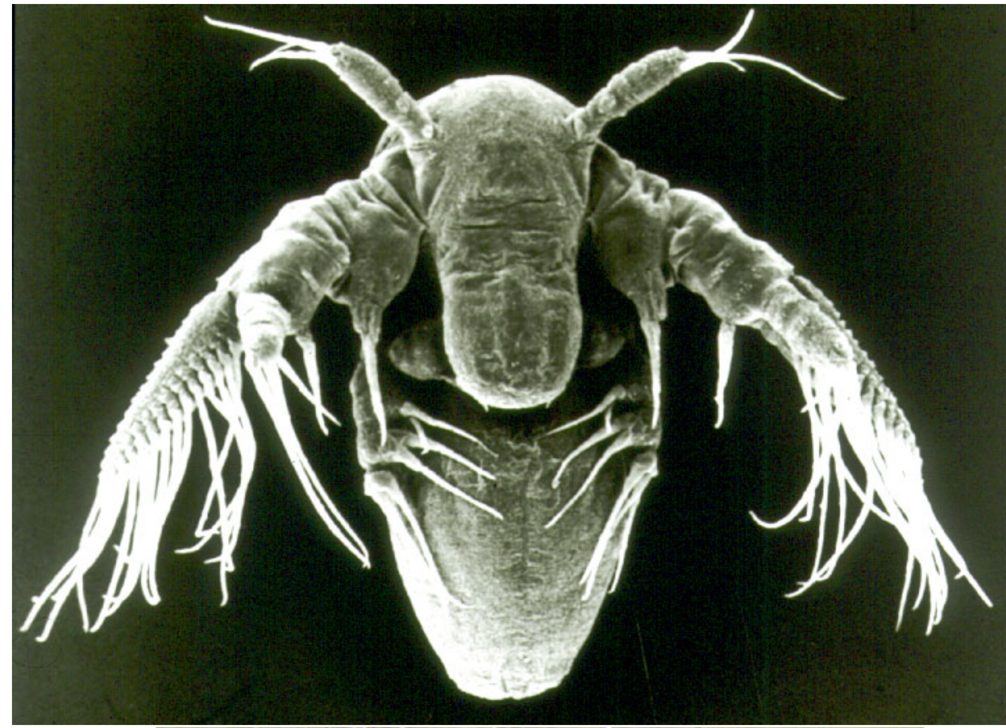
Embryology and Evolution

- Embryonic homologies show common decent.
  - Barnacle and shrimp
  - Tunicates and chordates
  - Starfish and chordates
- Charles Darwin used embryology to support his theories of evolution.

Vertebrate Embryos



Barnacle and Shrimp Larvae



Embryonic Homologies

- General embryonic structures become more specialized later in development.
- Evidence of evolution