Multiple choice (one point each; indicate the best answer)

1. The zona pellucida is synthesized by the
   a. sperm
   b. oocyte
   c. follicle cells
   d. corona radiata

2. At the point of fertilization, mammalian eggs have how many polar bodies?
   a. 1
   b. 2
   c. 3
   d. 4

3. In the sea urchin *Strongylocentrotus purpuratus*, sperm acrosome reactions are triggered by
   a. fucose sulfate.
   b. phospholipase.
   c. inositol trisphosphate.
   d. none of the above.

4. The mouse sperm acrosome reaction involves
   a. membrane fusion.
   b. \(\text{Ca}^{2+}\) concentration changes.
   c. G-protein activation
   d. all of the above

5. The SED1 protein is involved in
   a. mouse sperm capacitation.
   b. inducing mouse sperm acrosome reactions.
   c. mouse sperm-egg binding.
   d. mouse zona pellucida hardening.

6. During sea urchin fertilization, egg cytoplasm calcium ion content
   a. drops.
   b. rises.
   c. stays constant.
   d. disappears.

7. In general telolecithal eggs undergo ____________ cleavage.
   a. synchroblastic
   b. holoblastic
   c. teloblastic
   d. meroblastic
8. In sea urchin embryos, the 3rd cleavage (equatorial; produces equal-sized blastomeres), the spindles for each blastomere are probably
   a. located randomly.
   b. centered near the middle of the cell.
   c. clustered near the animal pole.
   d. clustered near the vegetal pole.

9. Sea urchin blastula cells
   a. form tight junctions with neighboring cells.
   b. form an epithelial layer.
   c. adhere to the hyaline layer.
   d. all of the above.

10. In early sea urchin embryogenesis, the presence of β-catenin will produce
    a. ectoderm.
    b. neurectoderm.
    c. endomesoderm.
    d. none of the above.

11. At the 64-cell stage, sea urchin blastomeres
    a. are uncommitted.
    b. are uncommitted, except for the micromeres.
    c. are specified, but not determined.
    d. are partially specified.

12. During sea urchin gastrulation the eventual oral area is specified by the presence of
    a. Nodal.
    b. Shh.
    c. Wnt8.
    d. BMP2.

13. During Drosophila egg formation, bicoid messages associate with
    a. dynein.
    b. the capped end of microtubules.
    c. the anterior pole.
    d. all of the above.

14. Drosophila acron and telson regions are specified by which genes?
    a. bicoid and nanos
    b. gurken and torpedo
    c. toll and pipe
    d. torso and torso-like

15. In Drosophila, eggs are activated
    a. prior to fertilization.
    b. by sperm binding.
    c. by pronuclear fusion.
    d. after the first nuclear division.
16. *Drosophila* eggs are described as  
   a. isolecithal.  
   b. mesolecithal.  
   c. telolecithal.  
   d. centrolecithal.

17. During *Drosophila* egg formation, the presence of Oskar is associated with  
   a. dynein.  
   b. the capped end of microtubules.  
   c. the posterior pole.  
   d. all of the above.

18. Gurken binds with which receptor?  
   a. Toll.  
   b. Torpedo.  
   c. Pelle  
   d. Patched.

19. In the amphibian blastula, mesoderm is induced by  
   a. paracrine factors and transcription factors.  
   b. VegT and Vg1.  
   c. endoderm.  
   d. all of the above.

20. During amphibian gastrulation, neural ectoderm is specified by the  
   a. epidermal ectoderm.  
   b. involuting mesoderm.  
   c. endoderm.  
   d. dorsal lip of the blastopore.

21. The cells on the leading edge of migration inside the amphibian gastrula are composed of  
   a. pharyngeal endoderm.  
   b. chordamesoderm  
   c. head mesoderm.  
   d. vegetal endoderm.

22. In amphibian embryos, involution occurs at the  
   a. dorsal lip of the blastopore.  
   b. dorsal and lateral lips of the blastopore.  
   c. dorsal, lateral, and ventral lips of the blastopore.  
   d. dorsal, lateral, ventral, and central lips of the blastopore.

23. Which of the following genes are associated with specification of the dorsal lip of the blastopore of amphibian embryos.  
   a. sonic hedgehog  
   b. siamois  
   c. ultrabithorax  
   d. none of the above
24. Areas of the amphibian embryo that are high in \( \beta \)-catenin, Vg1, and Nodal will likely form
   a. endoderm.
   b. organizer.
   c. ventral mesoderm.
   d. none of the above

25. In birds, the blastocoel is formed in the space between
   a. the primary and secondary hypoblasts.
   b. the area pellucida and area opaca.
   c. Koller’s sickle and the posterior marginal zone.
   **d. the epiblast and hypoblast.**

26. The primitive streak defines which axes?
   a. Anterior-posterior.
   b. Dorsal-ventral.
   c. Left-right.
   **d. All of the above.**

27. During implantation of the mammalian embryo, the cytotrophoblast gives rise to the
   a. amnion.
   b. chorion.
   c. yolk sac.
   d. umbilicus.

28. The syncytiotrophoblast
   a. lines the uterine blood vessels.
   b. creates the amnion.
   c. creates the yolk sac.
   **d. digests the endometrium tissue to create openings.**

29. In vertebrates, Hox genes
   a. are expressed in a 3’to 5’ manner.
   b. exist in multiple copies.
   c. have homologues in *Drosophila*.
   **d. all of the above.**

30. Nodal vesicular parcels, which are involved with establishing left-right asymmetry in mammals, contain
   a. BMPs
   b. dynein and kinesin.
   **c. Shh and retinoic acid.**
   d. none of the above.
**True / False** (one point each)

31. Cells with degraded cyclin B will not undergo division. **True / False**

32. In *Drosophila* embryos, the pole cells eventually form the acron and telson. **True / False**

33. Cavitation in mammalian embryos is induced by the trophoblast. **True / False**

34. Cortical granule release is considered an *early* post-fertilization event. **True / False**

35. Mammalian sperm capacitation requires gene transcription. **True / False**

36. The sea urchin acrosome reaction is triggered by elevated calcium ion concentration. **True / False**

37. The formation of the posterior marginal zone in chick embryos is influenced by egg rotation. **True / False**

38. The inner cell mass initiates hatching of the mammalian blastocyst. **True / False**

39. The trophoblast forms the chorion and yolk sac of the mammalian embryo. **True / False**

40. In mammals the posterior regions are determined by the presence of BMPs and FGFs. **True / False**

**Fill in.** 41 – 50 (1 point each)

- aortic arch
- atrium
- olfactory placode
- optic cup
- otic vesicle
- pharyngeal pouch
- somite
- spinal cord
- telencephalon
- vitelline vein

---

![Diagram of a developing embryo with labeled structures]
Define. Write a brief definition or description of *any five* of the following terms or phrases (2 pts. each):

51. Paralogous hox genes
   
   *Genes or gene clusters (in the case of Hox) that have been duplicated within taxa are termed paralogues. Vertebrate Hox genes have undergone multiple duplications, resulting in four paralogous clusters. Some paralogous Hox genes share functionality, while function in others have changed.*

52. Sperm capacitation
   
   *A series of physiological, biochemical, and physical maturational changes that mammalian sperm undergo in the female reproductive tract; necessary for sperm fertility. Maturational modifications include changes in membrane proteins and lipids, internal ionic content, and pH.*

53. Self-propagating calcium wave
   
   *A phenomenon where an initial release of calcium ions (from, for example, endoplasmic reticulum) stimulates calcium release from adjacent compartments, which stimulates further release, etc.*

54. The amphibian organizer
   
   *The dorsal lip of the blastopore, specified by the Nieuwkoop center, is termed the organizer. The region self-specifies and also specifies involuting ectodermal cells to mesodermal fates. In addition, the organizer sets up the Dorsal-Ventral axis of the amphibian embryo.*

55. Koller’s sickle
   
   *In cleavage stage chick embryo, the set of cells forming the inside border of the posterior marginal zone. This set of cells contributes to the formation of Hensen's node.*

56. Primitive streak
   
   *A linear formation of epiblast cells that forms during gastrulation in reptile, birds, and mammals through which ectoderm gastrulates to become mesoderm and endoderm. The primitive streak extends from the posterior margin of the embryo, thus establishing the anterior-posterior axis. Gastrulating ectoderm establishes the dorsal-ventral axis, and the streak forms a bilateral axis to establish left and right sides.*

57. Hensen’s node
   
   *The anterior-most section of the primitive streak is a localized thickening termed Hensen’s node. It is the equivalent of the amphibian organizer; self-specifying and capable of specifying gastrulating ectoderm cells.*

58. Fertilization cone
   
   *A cytoplasmic outgrowth from the egg that forms around the fertilizing sperm head. Motility supplied by actin microfilaments actively draws the sperm into the egg.*
Short Answer. Answer any five questions. Be certain to address all parts of the questions. (4 points each)

59. Cortical granules have four major components. List them and describe the specific function of each.

Serine protease: dissolves protein connections between vitelline envelope and egg membrane; clips bindin receptors and releases remaining sperm

Mucopolysaccharides: hygroscopic - elevate the fertilization envelope as they hydrate

Peroxidases: crosslink tyrosines in intervitelline space; harden fertilization envelope

Hyaline: forms a protective coating around the egg

60. Describe the control of the cell cycle before and after the mid-blastula transition in sea urchin embryos.

Mitosis is stimulated by MPF (mitosis promoting factor), which consists of cdc2 (cyclin-dependent kinase) and its activator, cyclin B. Active MPF phosphorylates nuclear components that are necessary to initiate mitosis. Cyclin B degrades quickly, inactivating cdc2. This degradation limits mitotic events, which do not resume until cyclin B has been resupplied.

In cleavage-stage embryos, cyclin B mRNA is supplied in maternally-derived stores; therefore, the cell cycle can continue without G phases, whereas post-cleavage-stage embryos institute G phases to transcribe new cyclin B transcripts (among other nuclear components).

61. β-catenin specifies cell identity in early embryos of several species. Describe two of these pathways.

β-catenin operates as a transcription factor in the Wnt signal transduction pathway. β-catenin exists in all cells, but is rapidly degraded because it is always associated with a molecular complex containing APC, Axin, and GSK-3, which adds a ubiquitin tag to the protein, labeling it for destruction. In the presence of the Dishevelled protein, GSK-3 activity is blocked, thereby releasing β-catenin to enter the nucleus and activate transcription.

Sea urchin – specifies micromeres and, with early veg2, specifies endomesoderm cells.

Amphibians – specifies dorsal fates

62. Cells move in a number of ways during gastrulation. Describe three types of cell movements and provide specific examples of their occurrence.

Involution – involuting marginal zone (ectoderm) at the dorsal lip of the blastopore throughout gastrulation

Invagination – dorsal lip of the blastopore at the start of gastrulation (bottle cells)

Epiboly – involuting marginal zone and ectoderm) throughout gastrulation

Convergent extension – ectoderm, throughout gastrulation

Migration – pharyngeal endoderm, etc (including various mesoderms), during involution
63. A) Place the following Drosophila gene groups in the proper order of expression:
- gap, homeotic selector, maternal effect, pair rule, segment polarity

B) Describe the general function of each group of genes.
Maternal effect, gap, pair rule, segment polarity, homeotic selector

Gene products (paracrine or transcription factors) or combinations of gene products from preceding expressions activate the expression of subsequent sets. In Drosophila, these successive sets of gene expression create finer patterns of segmentation, starting first with polarization genes (e.g. maternal effect genes bicoid and nanos), proceeding through specifying large regions (gap genes), then smaller segments and parasegments. Finally, segmental identity is established by the combination homeotic selector genes, which are differentially stimulated by the preceding gene products.

64. For each of the following cells, tissues, or structures list an analogous cell, tissue, or structure from another model species (specify which one) and describe what characteristics are analogous.

A. Sea urchin micromeres
- amphibian dorsal lip of the blastopore
- chick Hensen’s node
- mammalian node
Each are self-specified and direct the specification of all other tissues.

B. Mammalian blastocyst
- amphibian, echinoderm blastula
- fish, chick blastodisc
Each provides the structure for gastrulation to take place.

C. Chick primitive streak
- amphibian blastopore (or dorsal lip of the blastopore)
- echinoderm vegetal plate
- mammalian primitive streak (or node)
Each is the structure through which cells move into the embryo during gastrulation.

65. Describe the functions of the syncytiotrophoblast and cytotrophoblast.
The syncytiotrophoblast digests uterine tissue to provide space for the implanting embryo.
The cytotrophoblast adheres to the endometrium of the uterine wall, proteolyzes a portion of the wall to initiate implantation, secretes paracrine factors to attract maternal blood vessels, and forms the endothelial lining of maternal blood vessels in the placenta.

66. Describe the function of dynein ATPase in the establishment of left-right asymmetry in mouse embryos.
Cells in the mouse embryo node contain motile cilia that are powered by dynein ATPase to move in a clockwise direction (as seen from above), which causes a current flow in the nodal fluid. The current moves nodal vesicular particles, released under the influence of FGFs and containing sonic hedgehog and retinoic acid, from their origins in the cells surrounding the node to lodge in the right side of the node. Retinoic acid and Shh activate expression of Nodal on the left side.

Altering the nodal current flow or mutating dynein ATPase genes causes randomization of left-right asymmetrical organs.
Short Essay. Answer any two questions (10 points each). Be certain to address all parts of the questions and provide complete answers.

67. Describe the physiological processes that are involved in ensuring that mature sperm and eggs meet at the same time and place in mammals.

Eggs are ovulated and held for a time in the ampulla of the oviduct.

Sperm are transported to the isthmus of the oviduct, where they are held by the uterus and introduced in pulses into the oviduct.

Ejaculated sperm must undergo a maturation process termed capacitation in the female reproductive tract before they are able to fertilize the egg. Capacitation involves protein and lipid changes in the sperm membrane, changes in internal pH and ion transport.

Once in the oviduct, sperm are able to respond thermotactically to higher temperatures found near the ampulla.

Egg or follicular proteins may also act as chemoattractants to guide sperm towards them. In the vicinity of the egg sperm motility changes into a hyperactivated motion that increases the angle and velocity of the sperm tail movement and changes the linear movement pattern to one that keeps the cell in the same general area.

68. Describe the specification of *Drosophila* anterior and posterior regions with respect to the location, expression, and effect of *bicoid* and *nanos* genes.

The mRNA for bicoid and nanos are produced by the nurse cells and moved into the oocyte.

Bicoid messages associate with dynein at the capped (-) end of microtubules, which are polarized (with their capped (-) ends anterior, growing (+) ends posterior).

Nanos messages associate with the Oskar protein, which is associated with the growing (+) ends of the microtubules at the posterior end of the egg.

Expression of the bicoid and nanos genes in the anterior and posterior regions, respectively, results in formation of opposing protein gradients.

Bicoid protein acts as a transcription factor, inducing the expression of Hunchback, which specifies anterior fates. Bicoid protein also inhibits the translation of nanos genes, which limits nanos expression to areas lacking Bicoid.

Nanos protein acts as a transcription factor, inducing the expression of Caudal, which specifies posterior fates. Nanos protein also inhibits the translation of bicoid genes, which limits bicoid expression to areas lacking Nanos.
69. Describe how dorsal mesoderm and the dorsal lip of the blastopore are specified in amphibian embryos.

The dorsal lip of the blastopore is specified by a combination of β-catenin, VegT, Vg1, and nodal-related (Xnr) genes. VegT, Vg1, and Xnr genes are produced in relatively high concentration by the vegetal region. β-catenin is ubiquitous throughout the embryo, but is degraded everywhere but the future dorsal lip area. (NOTE – answers describing initiation by β-catenin in detail will be accepted).

Cortical rotation and kinesin activity moves the protein Dishevelled into the future dorsal lip area.
- vegetal cortex Dsh is attached to GBP and kinesin
- kinesin moves the complex toward the marginal zone
- cortical rotation moves the entire region towards the marginal zone
Once in the marginal zone, Dishevelled blocks the activity of GSK3, which otherwise participates in β-catenin degradation.

β-catenin acts as a transcription factor along with Tcf3, stimulating dorsal lip specifying genes such as siamois and goosecoid.