Survival Kit for the Physiology Lecturer

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"…And what guarantee do you have a longer life? Who will allow your course to proceed as you arrange it? Aren't you ashamed to keep for yourself just the remnants of your life, and to devote to wisdom only that time which cannot be spent on any business? How late is to begin relay to live just when life must end! How stupid to forget our mortality and put off sensible plans to our fiftieth and sixtieth years, aiming to begin life from a point at which few have arrived!"

Seneca (Spanish philosopher, circa 5 BC–AD 65),
"*On the Shortness of Life*" (2004)

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PRELUDE

This book is, as is often the case, a never-ending story. We started writing it when we had to make multiple choice questions (MCQs) exams for medical students. We had no idea where to start from and usually experienced a strong temptation to just 'copy and paste' the things we wrote on our slides as the exam date approached. With time and, of course, with many, many mistakes, we started making lists of the things we wanted the students to know.

The idea of this book is to ease the pain of anyone creating questions in physiology that are not only MCQs but also true/false questions and short questions. Together with the question given, numbers in brackets with different typography indicate the concepts worked in that particular question. At the very beginning of each chapter there is a list of concepts classified as key (standard typography), *advanced* (italics) and **specialised** (bold), matching the same typography type given in the question. This classification is strictly subjective and it doesn't reflect precisely whether the question is easy or difficult. Frequently, basic concepts can be very difficult to understand, but the most precise physiological mechanism can be very easy for students. It is also possible that some relevant concepts are missing. We aim for this book to be a scaffold on which you can lean. Feel free to change concepts and questions, according to your demands or those of your students. We provide also a teaching schedule at the beginning of each chapter. The same 'help yourself' rationale applies to the teaching schedule, which might be extremely pretentious or overly moderate depending on your course syllabus.

Many of the questions were made keeping in mind students from the health sciences. Nevertheless, there are also a few clinical and comparative physiology examples to illustrate some mechanisms or see things from another perspective.

After each part, we provide a stratified bibliography to assist with your needs as a teacher.

There is a final section in this book that contains no questions but pieces of advice gathered from our experiences working with students. It is plain

experience gained at the chalkboard side, without any scientific study or innovation.

This book is not perfect but such is life, enriched by imperfections and mistakes. Nonetheless, we hope you start (or continue) with this book on a beautiful journey and help others to enjoy the joys of physiology.

SECTION I:

CELL PHYSIOLOGY

PART I:

GENERAL PRINCIPLES

1.

HOMEOSTASIS

Summary: In this chapter, you will discover how living organisms regulate their vital functions.

Key concepts:

1. Regulation and types of response and feedback (positive feedback versus negative feedback).
2. Components of a basic response loop.
3. Many systems are implied for controlling one variable's value.
4. Cannon's principles.
5. Intercellular communication: types.
6. Dynamic equilibrium systems.

Advanced concepts:

1. Homeostatic mechanisms are energy-demanding compared to non-homeostatic mechanisms.
2. Amplifying a variable's value is a common mechanism in living systems.
3. Threshold.
4. Local versus reflex control.

Specialised concepts:

1. The malfunctioning of many regulation systems leads to pathology.

Teaching Schedule

Lecture 1

- Concept of homeostasis.
- Cannon's principles. Examples.
- Need for cell communication.

Lecture 2

- Cell communication types: analogies and differences.
- Receptor types. Threshold.

Lecture 3

- Range of the main physiological variables.
- Control mechanisms: response and feedback loops.

Lecture 4

- Endocrine versus nervous versus neuroendocrine reflexes; examples.
- Negative and positive feedbacks. Examples.
- Conclusions.

Questions

1. Is there any feedback during the generation of an action potential? [1]

a) Yes, and it's positive.
b) Yes, and it's negative.
c) There is no feedback.
d) Yes, it is negative on the depolarisation phase and positive in the repolarisation.

Answer a: This is a classic example of a positive feedback mechanism. A small depolarisation (from Vm to threshold) is amplified as a consequence of Na^{+}_{v} channel activation. A negative feedback would occur if a hyperpolarisation follows the depolarisation. Within the physiological context, the amplification of the stimulus is followed by a counterbalance repolarisation. This fact does not make two feedbacks 'in a row'.

2. From the following situations, mark the one that you think corresponds best to a dynamic equilibrium estate: [6]

a) Swimming one length front crawl.
b) Stopping in the middle of the swimming pool.
c) Treading water.
d) Swimming one length backstroke.

Answer c: Systems in dynamic equilibrium are very common in living systems. In this condition, the system apparently seems to stay still, although energy must be expended to counterbalance opposite forces, like it is done when treading water.

3. Which one of the following situations is a system in dynamic equilibrium? [6]

a) When the number of passengers hopping on and off the bus is equal.
b) When a battery is charging a resistor.
c) When someone is running on a treadmill at the same speed that the machine is operating.
d) None of the above situations describes a system in dynamic equilibrium.

Answer a: Same explanation as in question #2.

4. Which of the following mechanisms is required to maintain blood glucose levels close to the set-point? [3]

a) Insulin.
b) Glucagon.
c) Skeletal muscle.
d) All of the above.

Answer d: Many systems are usually required to maintain a physiological variable within its range. In this case, hormones and muscle (or fat) are involved in the maintenance of blood glucose levels.

5. In type-I diabetes, which part of the feedback loop is not working? [2]

a) Stimulus.
b) Efferent pathway.
c) Afferent pathway.
d) Effectors.

Answer b: Hormones are the efferent pathway in endocrine feedback loops. Often, "blood" is given as an answer, but blood carries many hormones with different 'messages'.

6. Taking into account the secretion of ADH in response to thirst, identify which element in this response loop is the stimulus, sensor, afferent pathway, integration centre, efferent pathway, effector and response. Which type of feedback loop is it? [1+2]

- Stimulus: Decrease in extracellular fluid (ECF) volume / increase in plasma osmolarity.
- Sensor: Hypothalamic / circumventricular organs osmoreceptors / arterial baroreceptors / juxtaglomerular apparatus.
- Afferent pathway: IX and X cranial nerves carrying baroreceptor signals / angiotensin II.
- Integration centre: ADH-containing neurons.
- Efferent pathway: ADH.
- Effector: Collector tubule-lining epithelial cells.
- Response: Water retention and concentration of urine / increase in blood pressure.
- Feedback loop: Negative.

7. Taking into account the action of oxytocin in labour, identify which element in this response loop is the stimulus, sensor, afferent pathway, integration centre, efferent pathway, effector and response. Which type of feedback loop is it? [1+2]

- Stimulus: Cervical stretch.
- Sensor: Mechanical receptors in cervix.
- Afferent pathway: Somatosensory pathways to the central nervous system (CNS).
- Integration centre: Oxytocin-containing hypothalamic neurons.
- Efferent pathway: Oxytocin.
- Effector: Smooth muscle cells lining the uterus.
- Response: Smooth muscle contraction.
- Feedback loop: Positive.

8. From the following regulatory mechanisms, which one is based on a negative feedback? [1]

a) Action potential's depolarisation phase.
b) Blood clotting.
c) Leukocyte attraction to a site of infection.
d) Muscle length adjustment through muscle spindles.

Answer d: Stretch receptors within skeletal muscles detect the lengthening of that muscle. Activation of intrafusal fibres within these receptors produces contraction of that same muscle (via activation of alpha motor neurons, decreasing muscle length).

9. From the following regulatory mechanisms, which one is based on a positive feedback? [1]

a) Blood glucose regulation.
b) Regulatory volume decrease.
c) pH regulation.
d) None of the described mechanisms is based on a positive feedback.

Answer d: All the mentioned regulatory mechanisms are based on a feedback loop model. The stimulus changes the variable in one direction and the response drives that variable in the opposite direction.

10. Which of the following tissues is implicated in maintaining body temperature in humans? [3]

a) Central nervous system.
b) Skeletal muscle.
c) Sweat glands.
d) All the mentioned tissues are related to body temperature control.

Answer d: This is a great example of how a given function is controlled by several systems. The hypothalamus, as part of the central nervous system, has a key role in thermoregulation as it contains temperature-sensing neurons and through peripheral effectors can modify body temperature. Skeletal muscle, while shivering, increases body temperature, and sweat glands, by sweat production, represent the miniature cooling system in the human body, facilitating heat loss.

11. Splenomegaly is a condition where the spleen is enlarged. On a patient with this condition (living at sea level without any pathological condition), the red blood cell (RBC) count would _____ as the spleen is the main organ where RBCs are _____. [1]

a) Decrease / produced.
b) Increase / produced.
c) Decrease / destroyed.
d) None of the above – the RBC would not change at all.

Answer c: The spleen is the main organ (together with the bone marrow) where RBCs are destroyed (not produced). Pathologies with an enlarged spleen usually cause the RBC count to drop.

12. Which one of the following is a system on a positive feedback loop basis? [1]

a) Glutamate excitotoxicity.
b) Blood glucose regulation.
c) pH regulation.
d) Cell volume regulation.

Answer a: During glutamate excitotoxicity, a spreading excitation occurs in the brain area. Usually, a cardiovascular accident causes the lack of oxygen and an ATP depletion. Thus, gradients cannot

be maintained in the affected area and depolarisation occurs, increasing neuronal firing. As glutamate is highly concentrated in synaptic vesicles in the brain, glutamate is released increasing the excitation.

13. From the following statements, mark which one is true: [1]

a) The depolarisation phase of an action potential corresponds to a positive feedback mechanism.
b) The repolarisation phase of an action potential corresponds to a positive feedback mechanism.

Answer b: n/a

14. Which of the following pairs is an example of antagonism? [4]

a) Insulin→glucagon effect on blood glucose level.
b) Sympathetic→parasympathetic system effect on cardiac contraction.
c) Thyroid→parathyroid hormone effect on calcium regulation.
d) All of the above are correct.

Answer d: All the cases given are good examples of antagonism.

15. To maintain a physiological value within its range does not require energy – true or false? *[1]*

a) True.
b) False.

Answer b: Animals expend a relatively high percentage of their ATP production just to work in a 'standby' manner to maintain body temperature, pH, gas levels, etc.

16. In any given cell, when ATP is depleted, cell volume regulation is still accomplished – true or false? *[1]*

a) True.
b) False.

Answer b: The Na^+/K^+ ATPase accomplishes several functions, primarily, sodium and potassium gradient generation. As in the intracellular fluid (ICF), the concentration of organic anions is

higher and there is a natural tendency for cations to move towards the ICF, thanks to their electrical gradient. Pumping sodium out of the cell, and expending ATP on it, decreases ICF osmolarity, making both ICF and extracellular fluid (ECF) osmolarities very similar. Without ATP, the ATPase stops working and will make the cell swell.

17. What happens when the threshold of calcium channels decreases in cardiac pacemaker cells? *[3]*

a) Firing frequency increases.
b) Firing frequency decreases.

Answer a: If a channel's threshold decreases, this means that a smaller intensity stimulus would open the channel more easily. Thus, depolarisation would occur at a faster pace in pacemaker cells.

18. Mydriasis and miosis as an adaptation to light are positive feedback mechanisms – true or false? [1]

a) True.
b) False.

Answer b: Mydriasis is the enlargement of the pupil, whereas miosis is the diminution of the pupil's diameter. When there is not enough light, mydriasis occurs to increase the amount of light reaching the retina; the opposite occurs in a brighter environment.

19. Sensitisation of a system can occur when: *[3]*

a) Threshold decreases.
b) Threshold increases.
c) The number of receptors increases.
d) Answers a) and c) are both correct.

Answer d: When a system responds 'better' to a stimulus of smaller than usual intensity, sensitisation occurs. This process may occur by increasing the number of receptors, either by increasing their synthesis or by them already being present in vesicles. The threshold can be modified by different post-translational modifications or, very frequently, by phosphorylation of the receptor.

20. Desensitisation of a system can occur when: *[3]*

a) Threshold increases.
b) Threshold decreases.
c) The number of receptors decreases.
d) Answers a) and c) are both correct.

Answer d: This is precisely the opposite situation compared to question #19. During desensitisation, the system 'accommodates' or stops responding to the stimulus. This can be achieved when there are fewer receptors or their threshold increases. In this case, a stronger stimulus would be needed for the system to respond.

21. When a mountain climber ascends 4,000 metres, blood oxygen levels will drop because of altitude. If a climber stays for a few days at such an altitude, this condition will lead to a release of erythropoietin (EPO), resulting in an increase in blood oxygen levels. This is a: *[4]*

a) Local response, negative feedback loop.
b) Reflex response, positive feedback loop.
c) Local response, positive feedback loop.
d) Reflex response, negative feedback loop.

Answer d: EPO stimulates the generation of red blood cells to increase oxygen levels in blood. This mechanism is stimulated by altitude-induced hypoxia.

22. When spinal motor neurons stop firing, as occurs in conditions such as ischemia, skeletal muscle relaxes. This is a demonstration of: *[4]*

a) Tonic control.
b) Phasic control.
c) Dynamic equilibrium.
d) Excitation.

Answer a: Skeletal muscles are stimulated at a low intensity by motor neurons to maintain body posture or facial expression, for instance. When these neurons stop working, acetylcholine is not released tonically, so the muscle is fully relaxed. This situation occurs, for instance, in hemiplegia or in facial nerve paralysis.

23. During inflammation, several cytokines are released at the infection site, for instance, by leukocytes. This is a clear example of: [1] *[2+4]*

a) Local control.
b) Amplification.
c) Positive feedback.
d) All of the above.

Answer d: Very frequently, a pathogen cannot be eliminated by a single immune cell. Thus, immune cells release cytokines and inflammatory factors to increase the number of immune cells at the infection site. This amplification, within the physiological range, does not spread away from the infection site.

24. During a septic shock, cytokines are released to the bloodstream by several immune cells. This is an example of local control – true or false? *[4]*

a) True.
b) False.

Answer b: During a septic shock, the pathogen reaches the bloodstream, causing many immune cells to respond in the same way as they would do locally. Nevertheless, the consequences affect the whole body (and compromise vital functions) as the amplification cascade in inflammation occurs at many vascular beds at the same time.

25. pH regulation by the renal or respiratory systems consists of a feedback loop which is: [1]

a) Positive.
b) Negative.

Answer b: pH regulation by several systems (including renal) is a classic example of negative feedback regulation.

26. Breast gland maturation after labour is due, in part, to over-secretion of prolactin (PRL). Before this, there is little secretion of PRL due to hypothalamic secretion of PIH (dopamine). This inhibition is an example of: [4]

a) Tonic control.
b) Negative feedback.

c) Positive feedback.
d) Antagonist control.

Answer a: Neurons in the hypothalamus inhibiting prolactin secretion do so by tonic secretion of dopamine, binding to its inhibitory receptors. This a good example of tonic inhibition.

27. Which of the following functions regulated under the parasympathetic and sympathetic nervous system would you consider to be an antagonistic effect or function? [4]

a) Male reproductive organ.
b) Sweating.
c) Erector pili muscle.
d) None of the above.

Answer d: This is a trickier version of question #14. As a rule of thumb, some organs in the body receive para and sympathetic innervation and their effect is antagonistic. Nevertheless, there are some exceptions as listed in this question: the male reproductive organ receives innervation from both divisions of the autonomous system but their effect is synergistic as the sympathetic facilitates ejaculation, whereas the parasympathetic induces vasodilatation and hence erection. Sweat glands and the erector pili muscle receive only sympathetic stimulation.

28. A climber ascending Mt. Everest is developing hypothermia. First, he feels cold and starts shaking, but after his core temperature has fallen below 32ºC, his muscles stop working. What will happen after muscular contraction ceases? Temperature _____ because of a _____feedback [1] **[1]**

a) Falls / positive.
b) Rises / negative.
c) Falls / negative.
d) Rises / positive.

Answer a: Several organs and systems contribute to body temperature maintenance. When moving, shivering or shaking, heat is generated in skeletal muscle. Without moving, temperature will fall; the more the temperature drops, the less we can move and so there will be a further drop in temperature and so on.

29. What type of intercellular communication is established when a B lymphocyte is activated by a Th cell? [5]

a) Contact-dependent junctions.
b) Paracrine communication.
c) Autocrine communication.
d) All of the above.

Answer d: This is a complex system where immunological synapse needs to take place, then genes are activated and begin the cytokine secretion phase that will both activate the secretory cell (B cells) and reinforce the Th cell for additional activation of a B cell.

30. In which of the following tissues would you be more likely to find GAP junctions? [5]

a) Heart.
b) Nerve tissue.
c) Skeletal muscle.
d) Epithelia.

Answer a: GAP junctions facilitate synchronisation of electrical activity, among other functions. In the heart, the presence of these junctions helps to synchronise contraction. Although there are some electrical synapses in the nerve tissue, in mammals this is not very frequent. There are no such GAP junctions in skeletal muscle and although there are GAP junctions in some epithelia, it is not as ubiquitous as in the heart.

2.

WATER MOVEMENT, CELL VOLUME REGULATION AND WATER BALANCE

Summary: The function of water compartments and how water moves into and out of these compartments is key for survival. Here, we find some questions to cover these topics.

Key concepts:

1. Osmolality and osmotic pressure drive water movement.
2. Osmolality does not depend on solute size.
3. Osmolality depends on dissolved particles.
4. Osmosis is a passive process.
5. Starling forces.
6. Oedema can result from variations in Starling forces.
7. Na^+/K^+ ATPase is a cell volume regulator.
8. Many transporters can counterbalance water gain or extrusion in many cells.
9. Brain and kidney control systemic water balance.
10. Vasopressin is a key regulator on water balance.
11. Some transmembrane proteins form pores for a few solutes and water.
12. Water balance is regulated on a negative feedback model.

Advanced concepts:

1. Some drugs modify vasopressin secretion.
2. Several osmolytes are synthetised to control cell volume homeostasis.
3. In hepatic failure, ascites occurs.
4. Blood albumin exerts an osmotic pressure, retaining water in circulation.

Specialised concepts:

1. Taurine is the main osmolyte in excitable tissues.
2. Lymphatics blockage occurs in elephantiasis, resulting in severe oedema.
3. Filtration changes with inflammatory states.

Teaching Schedule

Lecture 1

- Body water compartments. Percentages of total weight and total body weight.
- Ionic and chemical composition of body water compartments.
- Electroneutrality. Implications.
- Gibbs-Donnan equilibrium and Donnan effect. Functional relevance.
- Conclusions.

Lecture 2

- Osmosis. Osmotic pressure and Van't Hoff's Law.
- Osmotic pressure versus osmolarity and osmolality. Biological relevance.
- Water balance in living organisms (humans).
- Water content in food.
- Water balance regulation. Master role of the kidney.
- Conclusions.

Lecture 3

- Water movement between body compartments (I)
    - Intracellular and extracellular fluid.
    - Cell volume regulation: osmolytes.
- Conclusions.

Lecture 4

- Water movement between body compartments (II)
    - Interstitial fluid and plasma.
    - Starling forces.
    - Biological and pathological implications of Starling forces.
- Conclusions.

Questions

1. In the table below is shown the composition of a Ringer's solution:

Chemical	Concentration (mM)
NaCl	125
KCl	3
$NaHCO_3$	25
NaH_2PO_4	2
$CaCl_2$	1.5
Mg_2Cl	1.6
Glucose	25
Osmolarity	340 mOsm/l

For an experiment, sodium chloride is replaced by sucrose. Considering that sucrose and sodium chloride's molecular weights are 342.3 g/mol and 58.44 g/mol respectively, what will be the osmolarity of the final solution? [2]

a) 340 mOsm/l.
b) 400 mOsm/l.
c) 290 mOsm/l.
d) 256 mOsm/l.

Answer a: If the same number of moles of sodium chloride are replaced by the same number of moles of sucrose, then the total sum of particles in solution is the same and hence so is the osmolarity.

2. Sue is a laboratory technician who finds three beakers containing solutions of sodium chloride, potassium chloride and magnesium chloride. Each of these solutions is prepared at molar concentrations of 1.5, 3 and 4 mM respectively. She needs to calculate the osmolarity of these solutions to prepare an experiment. Taking the above into account, mark the correct statement: [3]

a) All of the three solutions have the same osmolarity.
b) The osmolarity of the potassium chloride solution is twice that of the sodium chloride solution.
c) The osmolarities of the magnesium chloride solution and the sodium chloride solution are equal.