

# Introduction

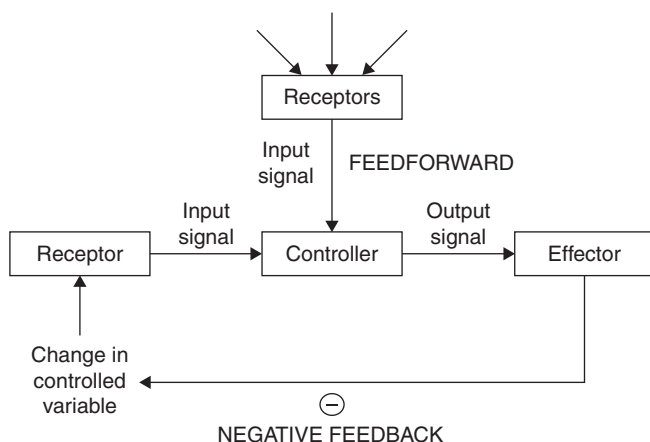
---

*Physiology* is the study of the mechanical, physical and biochemical functions of living organisms. All living organisms require a stable internal environment for survival. A large part of physiology is therefore about how we achieve this. In the absence of external challenges, this requires simply keeping the internal environment the same. In the face of challenges from the world outside, however, it requires the ability to resist change and respond in ways that tend to bring the state of the system back to normal. Most of physiology is therefore about *minimizing* the effect of change rather than *preventing* change itself.

This distinction is an important one. Each component of our internal environment interacts with innumerable others in innumerable ways. A change in one component will therefore have knock-on effects on others and controlling one is often only possible at the expense of another. Countering the effect of a change in one variable often requires changing another. If the O<sub>2</sub> content of the air we breathe falls, should we make do with less and keep our CO<sub>2</sub> levels normal or breath faster to inhale more O<sub>2</sub> and in so doing, blow off CO<sub>2</sub>? If we are short of NaCl, should we loose water and keep the concentration constant or conserve water to maintain volume but allow the concentration to change? If an organ requires an increase in blood flow, should we allow this increase at the expense of blood flow to other organs? In each case, the answer depends on which option poses a greater threat to the internal environment: it will often depend on both the severity and time course of the challenge.

Internal mechanisms are often able to minimise the impact of a change on the body as a whole. However, returning the system to its previous state usually requires alterations in the input or output of substances to or from the body. The impact of the loss of NaCl may be minimised in the short term by a range of mechanisms, but the lost NaCl must ultimately be replaced if the previous state of the body is to be restored. One of the biggest challenges in physiology is therefore balancing input and output.

How such control is achieved can be appreciated by considering the body as a generic *control system*. Information obtained from sensors (*receptors*) is transmitted to a control centre (*controller*), which is charged with the task of deciding what to do. Having made a decision, the controller then transmits a signal to some structure, or structures (*effectors*), thus directly or indirectly effecting a change in the variable. This change may involve using *feedback* or *feedforward*, separately or in combination (Fig. 1). In a *negative feedback system*, an effort is made to return the variable to its normal value. In a feedforward system, the body uses a variety of inputs to anticipate change, hoping to respond to it before it happens. Such control systems are truly fundamental to physiology and are discussed in more depth in the Appendix.



**Fig. 1.** Feedforward and negative feedback systems.

Appreciating which variables are most important to control and a knowledge of the factors, both internal and external, which influence these are therefore at the core of physiology. This book concentrates on these basic principles. Each of the major systems in the body is covered in turn followed by examples of how these systems interact to face common day-to-day challenges. Further Thoughts sections including additional material follows most chapters and an Appendix is provided at the end for those interested in the theoretical aspects of the subject.

We do not intend this to be another complete textbook of physiology: several excellent comprehensive texts already exist. Instead, we hope to stimulate interest, reflection and discussion and to encourage further reading. If this book conveys even a small part of our great enthusiasm for this fascinating subject, we will have achieved our purpose.

## A Note on Units and Symbols

We use standard scientific *Système International* (SI) units for the calculations. This system consists of the following *base units*:

ampere, A:	electric current
kelvin, K:	temperature
kilogram, kg:	mass
metre, m:	distance
mole, mol:	amount of substance
second, s:	time
candela, cd:	luminous intensity (not used in this book)

All other units can then be expressed in terms of these base units as *derived units*. The named units used in this book are as follows:

coulomb, C (A·s):	charge
volt, V ( $\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-3} \cdot \text{A}^{-1}$ ):	potential difference
farad, F ( $\text{C} \cdot \text{V}^{-1}$ , $\text{m}^{-2} \cdot \text{kg}^{-1} \cdot \text{s}^4 \cdot \text{A}^2$ ):	capacitance
ohm, $\Omega$ ( $\text{V} \cdot \text{A}^{-1}$ , $\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-3} \cdot \text{A}^{-2}$ ):	resistance to electric current
siemen, S ( $\text{V}^{-1} \cdot \text{A}$ , $\text{m}^{-2} \cdot \text{kg}^{-1} \cdot \text{s}^3 \cdot \text{A}^2$ ):	conductance to electric current
newton, N ( $\text{m} \cdot \text{kg} \cdot \text{s}^{-2}$ ):	force
joule, J ( $\text{N} \cdot \text{m}$ , $\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-2}$ ):	energy
watt, W ( $\text{J} \cdot \text{s}^{-1}$ , $\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-3}$ ):	power
pascal, Pa ( $\text{N} \cdot \text{m}^{-2}$ , $\text{m}^{-1} \cdot \text{kg} \cdot \text{s}^{-2}$ ):	pressure

However, in both physiology and medicine, units that are not part of the SI system are in common use. Those appearing in this book are as follows:

centimeter of water, cmH<sub>2</sub>O (1 cmH<sub>2</sub>O  $\simeq$  98 Pa): pressure  
 millimeter of mercury, mmHg (1 mmHg  $\simeq$  133 Pa): pressure  
 dalton, Da (one twelfth the mass of a <sup>12</sup>C atom,  $\simeq$  1.66 · 10<sup>-27</sup> kg):  
 atomic mass  
 litre, L (1 L = 10<sup>-3</sup> m<sup>3</sup>): volume

Non-SI units used for the measurement of pressure are explained in the Appendix. M is used to represent mol·L<sup>-1</sup> and square brackets are used to denote concentrations along with the following subscripts:

[ ]<sub>e</sub> extracellular concentration  
 [ ]<sub>i</sub> intracellular or inside concentration  
 [ ]<sub>o</sub> outside concentration  
 [ ]<sub>plasma</sub> plasma concentration

The following abbreviations are used to denote powers of ten:

nano, n: 10<sup>-9</sup>  
 micro,  $\mu$ : 10<sup>-6</sup>  
 centi, c: 10<sup>-2</sup>  
 milli, m: 10<sup>-3</sup>

## Normal Values

[K <sup>+</sup> ] <sub>i</sub>	140 mM
[K <sup>+</sup> ] <sub>o</sub>	5 mM
[Na <sup>+</sup> ] <sub>i</sub>	10 mM
[Na <sup>+</sup> ] <sub>o</sub>	140 mM
Resting nerve membrane potential ( $E_m$ )	-79 mV
Equilibrium potential for K <sup>+</sup> ( $E_K$ ) in nerve	-73 mV
Equilibrium potential for Na <sup>+</sup> ( $E_{Na}$ ) in nerve	+93 mV
Nerve membrane capacitance ( $C_m$ )	1 $\mu$ F·cm <sup>-2</sup>
Intra-alveolar pressures during quiet breathing	-1 cmH <sub>2</sub> O to 1 cmH <sub>2</sub> O

Average intrapleural pressures during quiet breathing	-5 cmH <sub>2</sub> O to 8 cmH <sub>2</sub> O
Partial pressure of O <sub>2</sub> in arterial blood ( $P_{aO_2}$ )	95 mmHg
Partial pressure of O <sub>2</sub> in alveolar gas ( $P_{AO_2}$ )	100 mmHg
Rate of O <sub>2</sub> consumption ( $V_{O_2}$ ) at rest	300 ml·min <sup>-1</sup>
Rate of O <sub>2</sub> consumption ( $V_{O_2}$ ) in extreme exercise	3 L·min <sup>-1</sup>
Rate of CO <sub>2</sub> production ( $V_{CO_2}$ ) at rest	200 ml·min <sup>-1</sup>
O <sub>2</sub> content of arterial blood	200 ml·L <sup>-1</sup>
Atmospheric pressure ( $P_{atmos}$ ) at sea level	760 mmHg
Saturated vapour pressure of water at body temperature	47 mmHg
Systolic arterial blood pressure (ABP)	120 mmHg
Diastolic ABP	80 mmHg
Mean ABP ( $\overline{ABP}$ )	95 mmHg
Mean systemic filling pressure (MSFP)	7 mmHg
Jugular venous pressure (JVP)	7 cmH <sub>2</sub> O
Cardiac output (CO) at rest	5 L·min <sup>-1</sup>
Venous return (VR) at rest	5 L·min <sup>-1</sup>
Right atrial pressure (RAP)	0 mmHg
Glomerular filtration rate (GFR)	125 ml·min <sup>-1</sup>
Renal blood flow (RBF)	625 ml·min <sup>-1</sup>
Plasma osmolarity	286 mOsm
Plasma pH range	7.34–7.44