Physiology of Organisms: Michaelmas Term lectures 2010-11

An Introduction to Physiology, Dr Matthew Mason

Lecture 1: Physiology, and organisms
This lecture will introduce the science of physiology, from historical origins to current research, and will present you with an overview of the Physiology of Organisms course, looking at some of the exciting areas which will be covered in future lectures. We shall review essential aspects of cell biology which you will need to know, and we will conclude by considering the classification of the organisms which will be important to the course, and their major physiological differences.

Lecture 2: Moving things around
This lecture will review some basic concepts that underpin a lot of important biology, with regard to transporting substances within organisms. We shall consider how molecules cross biological membranes, the principles of diffusion and osmosis, and the use of bulk flow in multicellular organisms. As an introduction to things to come, we shall briefly discuss analogies between hydraulic and electrical systems.

Lecture 3: Electrochemical gradients
In this lecture, we shall examine how a voltage can be generated when two solutions of differing ionic concentrations are separated by a semi-permeable membrane. As applied to cells, this forms the basis of understanding the origins of the resting membrane potential in an animal cell. Widening our focus, we shall examine how electrochemical gradients in physiology can be harnessed by different organisms to provide energy for active transport, ATP synthesis and (the subject of the next lecture course) action potentials.

Nerve, Synapse and Sense Organs, Dr David Tolhurst

Lecture 1: Communication between cells
Signalling between cells usually involves one cell secreting a chemical message that changes the activity of target cells. Paracrine signalling can rely on passive diffusion of chemical messengers, but only over very short distances. Sending messages within the body mostly takes energy. Neural versus endocrine control. Neural messages are quick and potentially precise. Overview of neurons, nervous system and reflex arcs. Negative feedback loops. Passive electrical signals do not travel far down nerves, and become blurred in time.

Lecture 2: The nervous impulse or action potential
The propagated action potential. The action potential is “all-or-none”. Threshold, refractory period. Myelin and conduction velocity. Ionic basis of action potential. Voltage-gated ion channels. Material versus message: axon transport. “Electrical” synapses (gap junctions). Chemical synapses: delay, unidirectional, subject to natural and unnatural modification.

Lecture 3: Synaptic communication between cells
The neuromuscular junction (NMJ). Pre-synaptic events at synapses. Ca++ as a ubiquitous messenger. Termination of synaptic action. Post-synaptic ionotropic actions of acetylcholine – the end plate potential. CNS synapses; neurotransmitters and drugs. Mainstream excitatory synapses – excitatory post-synaptic potentials. Spatial and temporal summation – allow control and decision making. CNS inhibitory synapses – inhibitory post-synaptic potentials. “Slow” synaptic mechanisms. G-protein mechanisms; cAMP.

Lecture 4: Making decisions, neuromodulation, and memory. Sensory receptors
Long-term interactions between nerves and muscles. Memory as long-term changes in synaptic strength. Pavlov’s dogs, Hebbian synapses; the NMDA receptor as one possible mechanism.

Sensory receptors and transduction. Graded receptor and synaptic potentials initiate all-or-none action potentials. Olfactory transduction – 1000 genes for G-protein coupled receptors.

Lecture 5: Eyes and ears: some examples of sensory coding
Rods, cones and rhabdomeres. Phototransduction in vertebrates. Different opsins and retinals in animals, Archaea and Protista. Evolution of opsins. Colour mixing: 1000 colours from three opsin genes. Melanopsin and circardian rhythms. Hair cells in the inner ear. Otoliths and gravity detection. Graded structure in the auditory cochlea – how to discriminate 3500 tones. Big eyes and ears versus small eyes and ears. Labelled line and pattern codes for sensory quality. Population and rate coding of intensity.

The Structure and Function of Muscle, Dr Hugh Robinson

Lecture 1
Survey of animal motility followed by more detail on muscle. The overall classification of muscle types. Then a focus on microscopic structure of skeletal muscle fibres, the sarcomere, the biochemistry of actin and myosin, the spread of the muscle action potential, the T-system, the triad, and the sarcoplasmic reticulum. Finally the structure of cardiac and smooth muscle will be described.

Lecture 2
The histological and physiological evidence for the sliding filament mechanism of muscle contraction. Length-tension and force-velocity relationships and their molecular interpretation. The calcium dependence of the contractile force. The crossbridge cycle and the molecular mechanism of the contractile process. Ciliary and flagellar mechanisms.

Lecture 3
The active state and twitch compared to tetanic contraction. Energy supply for contraction and the adaptation of muscles for different functions. Special properties of different types of striated muscle. Toadfish sonic muscle and insect flight muscle. Motor control mechanisms, and single-unit versus multi-unit smooth muscles. Prolonged contraction and rigor mortis.

Cardiovascular Physiology, Dr Dino Giussani

The overall aim of the lecture set is to introduce you to the heart and circulation across different species, to explain some of the complexities associated with closed circulatory systems and to highlight some of the problems faced by organisms when they distribute blood around the body.

Lecture 1: Overview of the cardiovascular system
In this lecture we will discuss what a cardiovascular system does, and why. Types of circulatory systems. Gross structure of the heart. The gross structure and classification of blood vessels. Comparative cardiac output and its distribution, highlighting species differences.

Lecture 2: Haemodynamics
This lecture will cover what makes blood flow, and why. Comparison of laminar, pulsatile and turbulent blood flow. Introduction to pressure waveforms and the measurement of arterial blood pressure. The concept of vascular resistance and its importance in real-life situations, such as during exercise.

Lecture 3: The heart
The final lecture will focus on the heart. Electrical and mechanical events in the cardiac cycle. Pressure-volume loops and their importance in health and disease. The heart's conduction system, the initiation of the heartbeat and the basic electrocardiogram.

Osmoregulation in Animals, Dr Stewart Sage

Lecture 1
This lecture will examine the need for osmoregulation in animals, the challenges presented by different environments and some of the strategies used to overcome them. Need for osmoregulation. Obligatory and regulated exchanges. Osmoregulators and osmoconformers. Osmoregulatory challenges and examples of their solutions. Aqueous environments: marine (elasmobranch and teleost fish, mammals, birds, reptiles); freshwater (teleosts, Amphibia). Terrestrial environments (mammals/desert mammals, birds).

Lecture 2
This and the following lecture will look at organs used for osmoregulation, commencing with that which is understood the best, the mammalian kidney. Osmoregulatory organs: filtration/reabsorption cf. secretion/reabsorption systems. Mammalian kidney. Gross anatomy. Nephron structure. Blood supply. Filtration, reabsorption, secretion.

Lecture 3
This lecture will complete our look at the mammalian kidney, concentrating on its functioning in osmoregulation. We will then look briefly at other vertebrate kidneys. Mammalian kidney: formation of dilute or concentrated urine. Basic renal handling of NaCl/Urea/H_2O. Countercurrent multiplication. Vasa recta. Non-mammalian vertebrate kidneys: amphibians, reptiles.

Lecture 4
In this lecture we will examine osmoregulatory organs other than the kidney in vertebrates, and osmoregulatory organs in invertebrates. We will end by looking at a problem closely associated with osmoregulation – the excretion of nitrogenous wastes. Extrarenal osmoregulatory organs of vertebrates: salt glands (elasmobranch rectal gland, salt glands of birds and reptiles). Gills (marine/freshwater fish). Invertebrate osmoregulatory organs: filtration/reabsorption (molluscs, crustaceans). Molluscan heart / "kidney". Crayfish antennal gland. Secretion/reabsorption (insects). Malpighian tubules/hindgut. Excretion of nitrogenous waste - examples of adaptation to suit osmoregulatory needs. Ammonotelic/ureotelic/uricotelic animals.

Animal Oxygen Acquisition and Respiration, Dr Mike Mason

Lecture 1
This lecture will quantitatively highlight the limitation of diffusion for gas exchange in larger organisms and introduce the concept of respiratory organs designed to overcome this limitation. This lecture will introduce the insect tracheal system; a simple adaptation that helps overcome this limitation of diffusion. Breathing, both in air and in water by the tracheal system will be investigated. I will introduce the lung and the gill as organs that have evolved to overcome the limitations of simple diffusion in large organisms. Special attention will be paid to a comparison of air and water as respiratory media, and the corresponding differential evolution of the respiratory organs of aquatic and terrestrial animals. This lecture will introduce the anatomy of the lungs and gill and their relationship to the circulation.

Lecture 2
In this lecture I will discuss the concept of lung and gill surface area and its effects upon gas exchange. I will focus upon the lung and gill circulations and introduce the 'pool' concept of the lung and the 'countercurrent' concept of the gill. Using basic physical laws I will introduce the requirements for the generation of a pressure gradient which underlies ventilation of both the lungs and gills. Special attention will be paid to the anatomical structure of the lungs and gills that allows for effective ventilation.

Lecture 3
This lecture covers the relevant information upon which the "Spirometry" practical class is based. I will introduce the use of spirometry for analysis of lungs volumes in health and in disease, and it will be necessary to refresh your memories regarding 'ideal or perfect gases' and the influence of pressure and temperature upon respiratory gas volumes. I will introduce the concept of partial pressures and show how the partial pressures of the respiratory gases change during inspiration. I will define the concepts of dead space, minute ventilation and alveolar ventilation and show how alterations in the pattern of breathing can dramatically modulate alveolar ventilation and the corresponding gas exchange between the arterial circulation and the environment. Two key quantitative relationships in pulmonary physiology, the alveolar ventilation equation and the alveolar gas equation, will be discussed for the purpose of explaining the relationship between alveolar ventilation and arterial gas composition. The lecture will conclude with an introduction to the role of arterial oxygen and carbon dioxide in the control of alveolar ventilation. Much of the information covered in this lecture will be reinforced in the Lent term practical class.

Animal Nutrient Acquisition, Dr David Tolhurst

Lecture 1: The problems, strategies and energetic-costs of animal nutrition
Autotrophic versus heterotrophic nutrition. Animals need organic molecules and minerals; their core organic molecules must be taken from other organisms. Symbiosis. Composition of the diet. Minerals, vitamins, and roughage. Digestion is hydrolysis. Parasitism. Intracellular digestion in simple animals. Extracellular digestion: "vats", intestinal tracts and chemical-engineering analogies. The enormous energetic cost of foraging, feeding, digesting and absorbing. What is safe or good to eat? The role of taste: sweet versus bitter, chilli and mustard.

Lecture 2: An overview of vertebrate digestion, using the functions and formation of saliva as a case study
A generalised vertebrate gastro-intestinal tract (GIT) including the liver. Composition of saliva, mucus. Functions of saliva in various animals. Protection of the GIT from infection and poisoning. Secretion of mucus, enzymes and other salivary proteins. Primary secretion of water and electrolytes; modification of secretion in the salivary ducts. Effect of flow rate. Matching blood supply to secretory activity. Overview of mechanisms of secretion by cells.

Lecture 3: The digestion and absorption of carbohydrates, ending with a description of the digestion of the near-indigestible chitin and cellulose
Carbohydrates in the diet (cellulose, chitin, starches and sugars). Salivary and pancreatic amylases. Enzymatic release of hexose monomers. Villi and microvilli. Facilitated diffusion and Na+-linked absorption of hexoses in small intestine. The liver and carbohydrates. Overview of mechanisms by which substances enter cells. Digestion of chitin. Digestion of cellulose by bacterial fermentation in foregut or hindgut. Production and absorption of volatile fatty acids; conversion to carbohydrate in the liver. Cycling of ammonia and urea in the rumen; bacterial production of amino acids and vitamins. Cats and Inuits.

Physiology of Organisms: Lent Term lectures 2010-11

Homeostasis, Dr Matthew Mason

Lecture 1: Introduction to homeostasis
This lecture will look at look at the principles of homeostasis, including a consideration of negative feedback. We will then look at the various types of chemical messenger found in animals, and consider different classes of hormones and their receptors in detail.

Lecture 2: The hypothalamus and pituitary
In this lecture we shall consider the role of the hypothalamus in integrating and dealing with competing physiological demands. We shall consider the anatomy and control of the pituitary gland, and the hormones released from the posterior and anterior parts. We shall consider oscillations due to delays in feedback and look at the importance of anticipatory signals, using osmoregulation as an example.

Lecture 3: The autonomic nervous system
In this lecture we shall consider the anatomical lay-out of the sympathetic and parasympathetic nervous systems. We shall look at the receptors for adrenaline and noradrenaline and also their physiological uses, concentrating on the control of the cardiovascular system and the fight-or-flight response. This lecture will also introduce you to some autonomic pharmacology.

Lecture 4: Integrated homeostatic responses
In this lecture we shall consider integrated homeostatic mechanisms involving both nerves and hormones. The main example will be the control of blood pressure: we shall look at the role of autonomic nerves in short-term control of blood pressure, in the face of challenges such as those imposed by haemorrhage and exercise.

Lecture 5: Homeodynamics?
Here we shall recognise that organisms cannot simply remain the way they are forever but must sometimes change – should "homeostasis" be renamed "homeodynamics"? We shall look at some physiological changes that occur in animals, focussing on biological rhythms, pheromones, metamorphosis and colour changes.

Plant Physiology: An Introduction, Dr David Hanke

In these lectures you will be introduced to the fundamental mechanisms that plants have evolved to allow growth in the varied environments of our planet. I will use our knowledge of plant genomes as a base to introduce the most fundamental aspects of plant life.

Lecture 1: Plants, genomes and germination
The first eukaryote to be completely sequenced was a plant. The information from this genome sequence will be used to explain both how a seed is stimulated to germinate, and how plants tell the time.

Lecture 2: Generating energy
Once a plant has germinated, the photosynthetic apparatus has to be assembled and used. I will introduce key aspects of both aquatic and terrestrial photosynthesis.

Lecture 3: Allocation of sugars to growing organs
Photosynthesis produces carbohydrates. In order to grow and reproduce, plants have to allocate vast quantities of sugars around the plant in a fast and co-ordinated manner. I will introduce the most important factors controlling allocation of carbohydrates to growing organs.

Lecture 4: Acquiring and distributing minerals around a plant
The sessile life of plants dictates that nutrient uptake from the soil must be efficient. One key factor is that roots are able to sense gravity and therefore grow down into the soil. The ability to move water and nutrients within the xylem are also fundamental. Gravitropism, water and nutrient movement will be assessed.

Plant Hormones, Dr Beverley Glover

Lecture 1: Key concepts
This lecture will discuss the important role of growth and development in plant physiology, a contrast to animal physiology. You will be introduced to the major classes of plant hormones, their chemical structure and biosynthesis. We will also consider the transport of hormones around the plant, and the receptors upon which they act.

Lecture 2: Embryogenesis and growth
Growth involves the processes of cell division, expansion and differentiation, and we will consider each, with examples. The cellulose cell wall poses a challenge to cell expansion in plants, and mechanisms for rendering the wall temporarily plastic will be examined. We shall also consider plant embryogenesis, the role of the apical meristems of the plant, and the control of shoot and leaf origins.

Lecture 3: Growth and acclimation
This lecture will begin by looking at below-ground development and the origins of roots. We will then consider how plant development is affected by changes in the environment to which the plant is exposed. We will also examine the mechanisms by which conditions in the plant and the world outside are monitored and translated into an appropriate response, for example using photoreceptors.

Lecture 4: Major life changes
In this lecture, we will investigate the mechanisms by which plant activities, both physiological and the linked developmental shifts, are entrained to changes in the environment so as to increase the chances of survival. The key example is the regulation of flowering and the decision to enter a reproductive state.

Plant Adaptations and Interactions, Prof. Howard Griffiths

The next five lectures will set the molecular basis of physiological adaptations in an ecological context. Plant productivity is vital – whether in terms of providing food and fuel, maintaining biodiversity, or ameliorating the impact of climate change processes. Diversity within plant communities is reflected in an array of underlying physiological mechanisms, which allow acclimation and adaptation to changing environmental conditions. We will explore how the demands of photosynthesis and water use respond to light availability, CO_2 supply and some resultant carbon concentrating mechanisms, and consider strategies to cope with environmental stress and enhance nutrient supply.

Lecture 1: Responses to fluctuating light
Physiological mechanisms allow some plants to thrive both in deep shade and full exposure, whilst others are restricted in their distribution. We will explore the distribution of PSI and PSII components between appressed and non-appressed thylakoid membranes, showing an amazing degree of spatial heterogeneity and lateral mobility. Such adaptations underpin the physiological acclimation of plants to contrasting light regimes, which in turn help to explain the ecological adaptations of sun and shade plants.

Lecture 2: Photosynthesis under changing carbon dioxide concentrations
Rubisco (ribulose bisphosphate carboxylase-oxygenase) is arguably the most important enzyme on earth and surprisingly inefficient. This lecture will consider the catalytic process and explain how CO_2 is fixed in preference to O_2, suggesting that evolution has made the best of a bad job. We will investigate the physiological implications for changing ambient CO_2, O_2 and temperature responses. With plants currently sequestering nearly two-thirds of the CO_2 released by man into the atmosphere, Rubisco is currently helping to stall climate change processes and biomass may provide an alternative source of energy in the short term.

Lecture 3: Photosynthetic carbon dioxide concentrating mechanisms
Pathways such as C4 and CAM are far more than just an adaptation to drought. We will examine the environmental pressures which have lead to the convergent evolution of such "photosynthetic turbochargers" in terrestrial and aquatic plants, as well as other comparable mechanisms in microalgae and cyanobacteria.

Lecture 4: Drought stress and salinity: molecular physiology of stress tolerance
Extreme summer droughts are likely to increase in frequency in the UK, and 6% of agricultural land globally has been affected by salinity in the past 50 years, so there is an increasing need to develop crops which are tolerant to environmental stress. We will consider general responses to abiotic stress using examples of photosynthetic gas exchange and the role of ABA when water is limiting, as well as osmotic adjustment and the molecular physiology of stress tolerance, and how this is reflected in the GM debate.

Lecture 5: Mutualistic interactions
Mutualistic interactions between bacteria, algae, fungi and plants will be addressed from the perspective of nitrogen fixation, mycorrhizae and lichens. Whilst the (nutritional) benefits of giving up some fixed carbon are clear for plants in many mutualistic interactions, deciding whether to tap into xylem or phloem is a sticky problem for parasites.

Physiology of Plant-Microbe Interactions, Dr John Carr

Lecture 1: Introduction to bacterial physiology
The bacteria are able to colonise almost all terrestrial environments. In this lecture we will examine the growth characteristics of bacteria in relation to their physiological strategies for nutrient accumulation and adaptation.

Lecture 2: Introduction to fungal physiology
There's more to fungi than mycorrhizae. Nutritional strategies define the growth and physiology of this Kingdom. Uptake mechanisms, nutritional physiology and growth mechanisms will be explored.

Lecture 3: The plant as a microbial host
One of the problems a plant faces is the inability to run away in the event of being attacked. A plant faces daily challenges from the microbial life around it as so many microbes are adapted to exploit it as a habitat and food supply. Here we will examine how microbes breach a plant's defences and how they adapt their nutrition to exploit the plant.

Lecture 4: The physiology of defence
We will introduce one last threat to a plant (and your food supply); viruses. Then we will go on to examine how a plant recognises it is under attack and changes its metabolism to limit the invasion.

Lecture 5: Microbial impact on plant physiology I
One of the most important economic aspects of infection of plants by micro-organisms is

decreased plant yield. In this lecture the ways in which microbial infection alters carbohydrate assimilation and translocation will be illustrated.

Lecture 6: Microbial impact on plant physiology II
The other big effect that pathogens have on plants is to cause wilting. Here you will see mechanisms by which microorganisms disrupt the normal processes used by plants to take up and translocate water.

Physiology of Organisms: Easter Term lectures 2010-11

Energy and Temperature Balance, Dr Andrew Murray

Lecture 1: Food and energy
This lecture will describe the main needs for and sources of energy in a balanced diet, how energy is stored between meals, and how energy stores are utilised in starvation. Definition of units and interrelationships. Energy demands of life (Basal Metabolic Rate, BMR); work and exercise. Daily consumption of carbohydrate, fat and protein. The need for "nitrogen" as well as kilocalories. Storage of energy reserves between meals. The vital role of the tiny carbohydrate reserves. "The wall" in the marathon. Overnight and prolonged fasting.

Lecture 2: Temperature regulation and heat production
This lecture will describe the origin of the heat produced by the body, and how the amount of heat changes or can be augmented. “Cold-blooded” versus “warm-blooded” animals. Core-temperature regulation in people is very precise, but the temperature of the extremities is allowed to fluctuate. Some countercurrent heat-exchange examples. Regulation of temperature depends upon balancing the body's heat production with heat loss (or gain) to the environment. Shivering. The thyroid gland and effects on the BMR. Brown adipose tissue (BAT).

Lecture 3: Control of heat gain and heat loss
This lecture will describe the mechanisms for controlling heat exchange between body and environment. Heat can be lost or gained by radiation, conduction and convection, and by vaporisation of excreted water. Behavioural controls. The skin: fat, fur, feathers, blood supply. Sympathetic nervous system effects on fur and cutaneous blood flow effectively change the thermal conductivity of skin. Sweat and "insensible perspiration".

Lecture 4: Hypothalamic control of food intake and temperature
This lecture will describe the brain mechanisms that control food intake and heat exchange between body and environment. Hypothalamic control of feeding: day-by-day weight control versus control of individual meal size. Some principles of negative feedback systems; effects of time delays on feedback systems. The hypothalamus and control of blood temperature. Interaction between cutaneous and hypothalamic temperature sensors.

Comparative Physiology: Form and Function, Dr Gregory Sutton

Lecture 1: Body size and shape
Introduction to allometric scaling and log-log graphs. How scaling analysis can be used to make predictions about the function of organisms. The diverse implications of large or small body size on the design and physiology of organisms.

Lecture 2: Scaling of metabolism with body size
How does metabolic rate scale with body size? Is there a universal scaling law for unicellular and multicellular organisms, animals and plants, ectotherms and endotherms? Scaling of maximal sustained and resting metabolic rate and physiological time.

Lecture 3: Biomaterials
Organisms not only have complex morphological structures but they also consist of biomaterials which have been optimised for different functions and vary widely in their physical properties. Parameters to characterise material properties. Examples of animal and plant biomaterials and their functions.

Lecture 4: Support systems (animals)
Larger animals and plants require support systems for stability. The design of animal hydrostatic skeletons as well as endo- and exoskeletons. Structure and mechanical properties of vertebrate bone, bone remodelling and reaction to mechanical stresses.

Lecture 5: Support systems (plants)
How do trees, the tallest organisms on earth, support their enormous weight and stand up to the wind? Can trees react to mechanical stresses like bones? How is water lifted up to the crown?

Lecture 6: Locomotion
Physiology and biomechanics of animal locomotion on land, in particular walking and running. When and why do animals change gaits? How does elastic energy storage contribute to running? Why do muscles perform positive and negative work? Metabolic cost of transport.

Comparing the Physiology of Plants and Animals, Dr Julian Hibberd & Dr Christof Schwiening

This single seminar, co-presented by an animal physiologist and a plant scientist, represents an informal session in which some of the concepts of plant and animal physiology that you will have learned about over the year are put together in a comparative way.