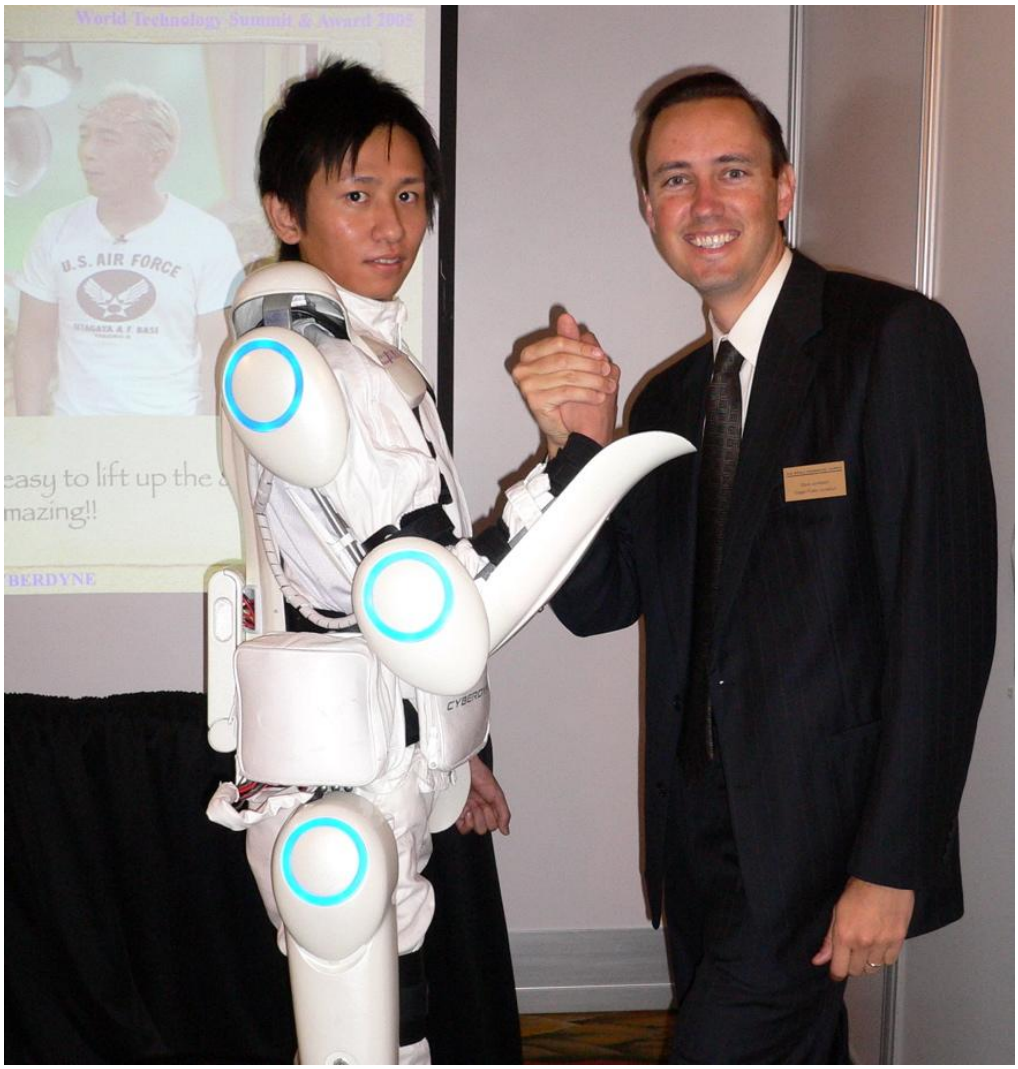
Interdisciplinary Science

PA2015

Man and Machines



University of Leicester

Contents

Welcome

Man and Machines covers topics from the fields of biophysics and physiology - you will research in depth the structure and function of some of the systems of the human body from biological, biochemical and physical perspectives.

Module Authors

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Problem Statement

The Department for Innovation, Universities and Skills (DIUS) has decided to use the 2012 Olympics in the UK to attract students to scientific research.

As the first part of this proposal, their marketing executives decided it would be a good idea to find out what motivates students by running a competition offering a prize for questions about sports science submitted by students. The DIUS will then capitalise on these interests by providing teachers with comprehensive scientific answers to selected questions.

The DIUS will publish these answers on a website.

Among the questions submitted by students were the following:

Question 1 Why are carbohydrates so important to athletes?

Question 2 Why do we have to warm up before we exercise?

Question 3 Why do you get sore muscles when you move house?

Question 4 How much weight can you lose by running on the spot?

Question 5 Why do you go red when you exercise?

The DIUS has identified that the answers to most of these questions are interdisciplinary in nature.

Staff

Prof. Derek Raine	Physics
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Learning Objectives

At the end of this module you should be able to:

Biology

- Give the laws of thermodynamics, and describe their importance in relation to metabolism.
- For the four main parts of metabolism, glycolysis, citric acid cycle, the electron transport chain and chemiosmosis you should be able to:
    - Give the cellular location where they occur.
    - Give the overall reactants and products.
    - Describe their importance.
- Describe, in broad terms only, how nutrients other than glucose are metabolised.
- Describe the general mechanism and importance of coupling to metabolism.
- Define and use the following terms with confidence: exergonic and endergonic reaction, anabolism and catabolism.
- Describe how to measure the volume of respired air, and how to find the concentrations of oxygen and carbon dioxide in it.
- Calculate a respiratory quotient for a person, and use it to determine the type of food they are burning.
- Calculate how efficiently you can convert energy production in the body to external work.
- Describe the structure of a skeletal muscle.
- Describe in detail the mechanism by which a muscle contracts.
- Describe what is meant by the terms ‘antagonistic pairs’ and ‘coactivation’.
- Describe the nature and function of the three types of muscles fibre S, FR and FF.
- Describe the effects of changes in the number of muscle fibres innervated by each motor neuron.
- Describe the structural and functional differences between pinnate and pennate muscles.
- Describe why an isometric contraction still requires energy.

Physics

- Define and use the following terms with confidence: open and closed systems, entropy, Gibbs free energy and work.
- Define centre of mass in terms of moments and calculate it for various simple shapes.
- Calculate potential energy as *mgh*.
- Model a complex mass distribution in terms of simple components; quote the formulae for the volumes of simple shapes.
- Convert between calories and Joules.
- Define stress and strain; use Hooke's law; calculate elastic energy.
- Use video capture software.
- Use conservation of mass to calculate fluid flow rates in steady flow.
- Use Poiseuille's formula for flow in a pipe.
- Describe the effects of viscosity on fluid flow.
- Define mean free path and collision cross-section.
- Define thermal conductivity and heat capacity.
- Recall Fick's law and the diffusion equation.
- Use Femlab to model the diffusion equation.

Reading List

Books

- Sutton, J. (1998) *Biology*. PalgraveMacMillan.
  - Chapters 8, 9, 15, 19 & 24.
- Campbell, N. & Reece, J. (2005) *Biology, 7th Ed*. Pearson.
  - Chapters 1.2, 8, 9, 40, 41.1, 42 & 49.
- Breithaupt, J. (2003) *Physics, 2nd Ed*. Palgrave Macmillan.
  - Chapters 6.5, 7, 8.1-8.3, 12.1, 12.2, 25 & 26.
- Tipler, P.A. (1999) *Physics: 4th Ed*. Freeman Worth.
  - Chapters 6.1, 6.3, 6.4, 7.1, 7.2, 8.1, 11.3, 12.1-12.4, 12.8, 13.1, 13.2, 13.4 & 21.4.
- Berg, J.M., Tymoczko, J.L., Stryer, L. (2007) *Biochemistry: 6th Ed*. Freeman.
  - Chapters 8.1, 8.2, 11.1, 11.2, 15, 16, 17, 18

Facilitation Sessions

Facilitation Session 01

Pre Session Preparation

Read

- Biology (Sutton): chapter 8
- Biology (Campbell & Reece): chapters 1.2 & 8
- Physics (Breithaupt): sections 12.1 & 12.2
- Physics (Tipler): sections 6.1, 6.3, 6.4 & 11.3

Introduction to Module

An introduction to the module as a whole with a brief overview of the various topics that will be covered over the following weeks. The Problem Statement and deliverables will be introduced and initial thoughts will discussed as a class.

Group Discussion: What is energy?

In your groups discuss the topic of energy using the pre-session reading as a starting point. You may like to use the following questions to guide your discussion:

- What is energy and what forms can it take?
- How is energy converted from one form to another?
- What is done when it is converted?
- How does this topic relate to the problem statement and deliverables?

Facilitation Session 02

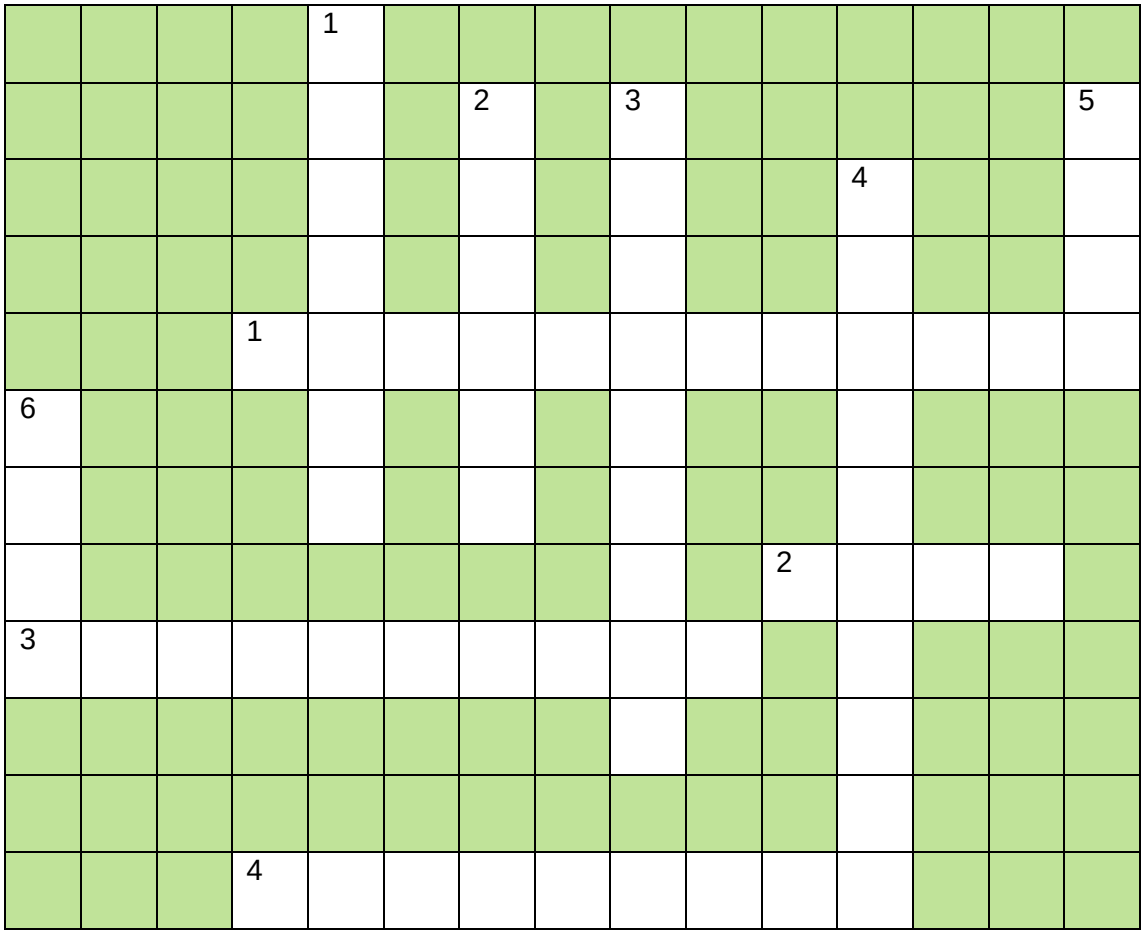
Pre Session Preparation

Read

- Biology (Sutton): chapters 8 & 9
- Biology (Campbell & Reece): chapters 9 & 41.1
- Physics (Breithaupt): section 12.1 & 12.2
- Physics (Tipler): section 6.1, 6.3, 6.4 & 11.3

Group Activity: Work, Energy and Metabolism

Within your groups complete the crossword below. Use the answers to guide your discussion of the topics of work, energy and metabolism.



Clues:

Across:	**Down:**
1. The first law of thermodynamics involves the application of this principle applied to energy. 2. When energy is transformed, this is done. 3. This is a reaction which results in a gain of free energy to the system. 4. The production of ATP from ADP and phosphate is an example of this.	1. This is a measure of disorder or randomness. 2. In this type of system, new reactants are not added, and products are not removed. 3. This is a reaction which results in a gain of free energy by the surroundings. 4. The breakdown of glucose into smaller particles is an example of this. 5. This type of system is much more common in biology. 6. This type of energy is potentially available to do work.

Facilitation Session 03

Pre Session Preparation

Read

- LSII – part 2: “Metabolic Rate and Energy Consumption” laboratory script

Group Preparation: Metabolic Rate and Energy Consumption

Within your groups read the “Metabolic Rate and Energy Consumption” laboratory script prepare a laboratory plan.

Group Discussion: Brainstorming

Within your groups go back over the brainstorm diagram created during the first session and identify which elements you have investigated and add any additional ideas you have had in the meantime.

Start to create a rough outline for the whole website using the brainstorming diagram as a guide.

Facilitation Session 04

Pre Session Preparation

Read

- Biology (Sutton): chapters 8, 9 & 15
- Biology (Campbell & Reece): chapters 9 & 41.1

Class Discussion: Metabolic Rate and Energy Consumption

As a class discuss the outcomes of the laboratory session.

- Did you achieve all of your aims?
- What did you discover?
- What went well and would you make any changes to your method if you did the session again?
- Can any of your results be used in the deliverable? How would you display them?
-

You should take this opportunity to complete any of the calculations that you did not attempt in the laboratory session.

Group Discussion: Cells & Metabolism

As a group review your metabolism notes from last week and describe the uses of energy within cells (mechanical, transport and chemical). You may like to consider the following questions as a starting point for your discussion:

- Which of these play a part in muscles?
- Which is the most significant and why?
- Why is homeostasis important to the body as a whole and metabolism in particular?

Facilitation Session 05

Pre Session Preparation

Read

- Biology (Sutton): chapters 19 & 24
- Biology (Campbell & Reece): chapters 40, 42, 49.5-49.7

Group Discussion: Muscle Structure and Function

Within your groups discuss the topic of muscle structure and function. The following are several questions that you may like to base your discussion on:

- What is the structure and function of muscles?
- What is isometric contraction?
- Can muscles act independently; what is meant by “coactiviation”?
- What goes wrong when you are tired?
- How and why does this affect muscle contraction?

Facilitation Session 06

Pre Session Preparation

- LSII – part2: “Muscles” laboratory script

Group Activity: Website Plan

In your group continue to work on your website plan. Think about how the pages relate to each other and the content to be covered on each page.

Group Preparation: Muscles

Within your groups read the “Muscles” laboratory script prepare a laboratory plan.

Facilitation Session 07

Pre Session Preparation

Independent research is encouraged

Class Discussion: Muscles laboratory session

As a class discuss the outcomes of the laboratory session.

- Did you achieve all of your aims?
- What did you discover?
- What went well and would you make any changes to your method if you did the session again?
- Can any of your results be used in the deliverable? How would you display them?

Group Discussion: Metabolism and Function

In your groups discuss the links between muscle metabolism and function. What happens when the blood glucose level is insufficient to meet the needs of the muscle? How is this information conveyed?

Facilitation Session 08

Pre Session Preparation

- Physics (Breithaupt): chapters 7 & 26
- Physics (Tipler): sections 7.1, 7.2, 8.1, 12.1-12.4 & 12.8.

Group Discussion: Rigid Body Dynamics

Within your groups discuss rigid body dynamics using the topics covered in the reading above and the “Ridged Body” Expert session as a starting point.

It is important that you understand the basic principles of this topic, however, you should also be aware how it links in with the overall focus of the module. How will you use this topic to illustrate key concepts on your website?

Facilitation Session 09

Pre Session Preparation

- Physics (Tipler): section 12.8

Group Discussion: Stress and Strain

Within your groups discuss the topic of stress and strain using the topics covered in the reading above and the “Ridged Body” Expert session as a starting point.

It is important that you understand the basic principles of this topic, however, you should also be aware how it links in with the overall focus of the module. How will you use this topic to illustrate key concepts on your website?

Facilitation Session 10

Pre Session Preparation

Read

- Physics (Breithaupt): sections 8.1-8.3
- Physics (Tipler): sections 13.1 & 13.2

Group Discussion: Fluids at Rest

Within your groups discuss fluids at rest using the topics covered in the reading above as a starting point. It is important that you understand the basic principles of this topic, however, you should also be aware how it links in with the overall focus of the module. How will you use this topic to illustrate key concepts on your website?

Prepare a series of questions for the “Fluids” Expert session.

Facilitation Session 11

Pre Session Preparation

- Physics (Breithaupt): sections 8.1-8.3
- Physics (Tipler): sections 13.1, 13.2, 13.4 & 18.5

Group Discussion: Fluids in Motion

Within your groups discuss fluids in motion using the topics covered in the reading above as a starting point. In addition to these sections listed above you should also research:

- Fick's Laws of diffusion
- The collision cross section of particles within a fluid
- Mean free path of particles within a fluid

It is important that you understand the basic principles of this topic, however, you should also be aware how it links in with the overall focus of the module. How will you use this topic to illustrate key concepts on your website?

Prepare a series of questions for the "Fluids" Expert session.

Facilitation Session 12

Pre Session Preparation

- Physics (Breithaupt): sections 6.5 & 25
- Physics (Tipler): section 21.4

Group Discussion: Heat Flow

Within your groups discuss the topic of heat flow and thermal conductivity topics covered in the reading above as a starting point.

It is important that you understand the basic principles of this topic, however, you should also be aware how it links in with the overall focus of the module. How will you use this topic to illustrate key concepts on your website?

Facilitation Session 13

Pre Session Preparation

Independent research is encouraged

Class Discussion: Femlab

As a class discuss the outcomes of the laboratory session.

- Did you achieve all of your aims?
- What did you discover?
- What went well and would you make any changes to your method for the next session?
- Can any of your results be used in the deliverable? How would you display them?

Group Discussion: Femlab

As a group expand upon the class discussion. Decide what results you want to take in the next Femlab session. Think how you would apply these results to the deliverable.

Facilitation Session 14

Pre Session Preparation

Independent research is encouraged

Group Work: Deliverables

You are advised to spend this facilitation session finalising work on your deliverables. It is in your own best interest to have at least a partially complete draft of your deliverable available to get feedback from your facilitator. This is the last opportunity to ask questions relating to the course.

Deliverables

Please name your deliverables in accordance with the standard naming convention (see the handbook for details). A sample filename is provided for you to cut and paste - please complete with submission date and username/group letter as appropriate.

All deliverables to be submitted to iscience@le.ac.uk

Please note that although deliverable deadlines (except for CLEs) are at the end of the module, you are strongly urged not to leave all work on the deliverables until the final weekend! In particular, if you would like formative feedback on your works-in-progress from your facilitator and/or experts, please provide them with draft copies in good time.

DELIVERABLES	TYPE	FILENAME	DUE	WEIGHTING
CLE01:	I	PA2015_I_CLE01_*username_date*.pdf	Week 2, Day 1	30%
CLE02:	I	PA2015_I_CLE02_*username_date*.pdf	Week 3, Day 1	
CLE03:	I	PA2015_I_CLE03_*username_date*.pdf	Week 4, Day 1	
CLE04:	I	PA2015_I_CLE04_*username_date*.pdf	Week 5, Day 1	
D01: Website Plan	G	PA2015_G_D01_WebsitePlan_*groupletter_date*.pdf	Week 5, Day 1	10%
D02: Introductory Webpage	G	PA2015_G_D02_HomePage_*groupletter_date*.zip	Week 5, Day 1	10%
D03: Focus Webpage	I	PA2015_I_D03_Focus Webpage_*username_date*.zip	Week 5, Day 1	50%

Core Learning Exercise 01

1. Draw a molecule of ATP. [5]

2. Complete the table: [15]

	Key reactants	Key products/outcomes	Location
Glycolysis			
Citric acid cycle			
Electron transport chain			
Chemiosmosis			

3. Explain the importance of coupling in the context of energy utilisation in the cell. [5]

4. Explain the significance of the electron transport chain to energy utilisation in the cell. [5]
5. How does the second law of thermodynamics help explain the diffusion of a substance across a membrane? [5]

6. Using a specific reaction of your choice from the citric acid cycle, describe how a lot of reactions linked to metabolism can be considered redox reactions. [5]

7. Describe in detail a specific example (either mechanical, transport or chemical) of how ATP is used to do cellular work [5]

8. Explain why anaerobic respiration is not as efficient as aerobic. [5]

9. Explain what features of glycolysis led scientists to believe that it may have evolved very early in the history of life. [5]

10. The human diet does not consist entirely of glucose. Explain what other nutrients can be used as fuel, and how they link in to glycolysis and/or the citric acid cycle. [5]

Core Learning Exercise 02

1. Describe the structure of a skeletal muscle. [10]

2. Describe the structure of the contractile unit of the muscle. [10]

3. Describe the changes which occur within the sarcomere as a muscle fibre contracts. [5]

4. Explain why muscle fibres contain a large number of mitochondria? [5]

5. a) Define the term 'motor unit'.
   b) List three key facts about each of the following types of motor unit: S, FR, FF. [15]

6. What difference might you expect in the number of muscle fibres innervated by each neuron in the muscles of the hand compared to the bicep muscle? Give a reason for this difference. [5]

7. Give three differences between parallel fibres and pinnate fibres. [5]

8. What does the term 'tetanus' refer to, in the context of muscles: [2]

9. a) Explain, using your knowledge of metabolism and muscles, why it is important to warm up before you exercise. [5]
   b) Explain why you go red when you exercise strenuously. [5]
   c) Explain why studying systems in the body (such as circulatory, locomotive, etc) in isolation is not really possible. [5]

Core Learning Exercise 03

1. a) What is the moment of the system in figure 1 about the point *X* a distance *x* from one mass?
   b) What is the condition on *x* for the moment to be zero?
   c) Where is the centre of gravity of the system?

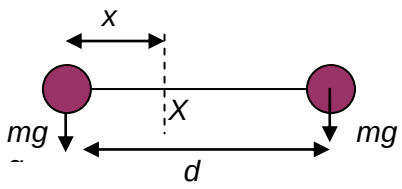


Figure 1

In figure 2 the right hand sphere has been replaced with one twice as massive.

   d) What is the moment of the system in figure 2 about a distance *x* from the smaller mass?
   e) Where is the Centre of Gravity of the system?

[15]

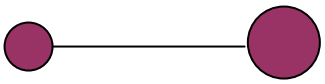
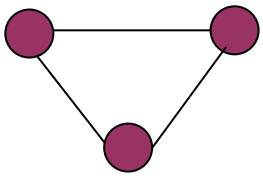
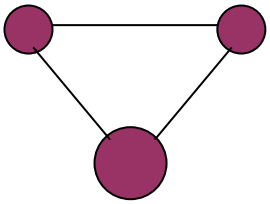


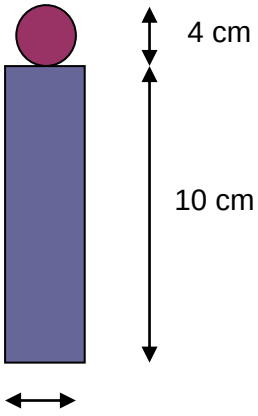
Figure 2

2. Where is the centre of mass of the following? Assume the connecting lines are massless and that the mass of the larger circles is twice that of the smaller ones. [10]





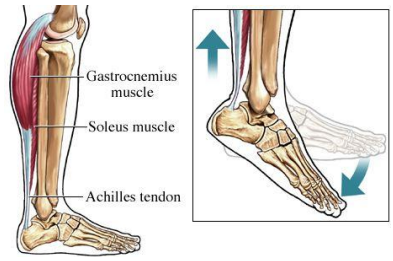
3. A sphere of radius 2 cm and density 10^3 kg m^{-3} is placed on top of a column of height 10 cm, radius 2.5 cm and density 400 kg m^{-3}. Where is the centre of mass of the sphere and cylinder? [10]



What is the change in gravitational potential energy in raising the object by 10 cm? [5]

4. Work out (a) the stress and (b) the stored energy in the Achilles tendon from the following data: [5]

Force exerted on the tendon = 4700 N
Cross section = 89 mm^2
Length = 250 mm
Extension = 15 mm



c) Compare this with the average kinetic energy of a marathon runner. [5]

d) Show that running shoes make relatively little contribution to the stored energy. (Rubber has a Young's modulus of < 0.36 N mm^{-2}.) [5]

5. During running the upward force on the femur is 6400 N. Its Young's modulus is 17 900 N $mm^{-2.}$ It has a length of 500mm and a cross sectional area of 330 mm^2. How much energy is stored in the femur at maximum compression? [5]

How much shorter is the femur when you are you standing up? [5]

6. Kangaroos have long tendons. What advantage does this give them – answer TRUE or FALSE to the following statements? [5]

a) They have a large stride length allowing them to cover more ground in less time.
b) Their tendons will be under less stress so less likely to suffer injury.
c) They can store more elastic energy allowing them to cover larger distances with less energy expenditure.

Core Learning Exercise 04

1. Which of the following will (in theory) accomplish a change by a factor of 4 in the rate of flow of a viscous fluid through a pipe? [10]

   a) Increase the length by 4
   b) Increase the pressure at one end by a factor 2 and decrease the pressure at the other end by a factor of 2
   c) Decrease the viscosity by a factor of 4
   d) Increase the diameter by a factor of 2

2. Assuming blood to be incompressible, by what factor is the speed of blood flow changed in a constricted artery the diameter of which has been reduced by half? [5]

3. The maximum flow rate at which the heart pumps blood into the aorta is about 500 $cm^3\ s^{-1}$. The aorta has a diameter of 2.5 cm and blood has a viscosity $\eta = 10^{-3}$ Pa s.
   a) Find the pressure drop along unit length of the aorta. [5]
   b) How much power does the heart expend pushing blood along a 10 cm section of the aorta? Compare your answer with the BMR of an average individual. [5]

4. a) Derive Fick's law relating the flux of particles to the density gradient in a gas. [5]

   b) How is the diffusion constant related to the mean speed of fluid particles (*v*) and their mean free path (λ)? [5]

   c) Hence show that in a fluid of density *n* particles of mass *m* per unit volume, at temperature *T* the diffusion constant is given by:

$$D = \frac{1}{n\sigma}\left(\frac{3kT}{m}\right)^{1/2}$$

   where σ is the collision cross section. [5]

   d) Assuming that particles carry an energy 3kT/2, derive an expression for the thermal conductivity of a gas. [5]

5. a) From Fick's law derive the diffusion equation: [5]

$$\frac{\partial n}{\partial t} = D\frac{\partial^2 n}{\partial x^2}$$

   b) Show that a constant density gradient $n(x) = -cx$ results in a steady rate of flow of mass. [5]

   c) Verify that $n(x,t) = t^{-1/2} exp\left(-\frac{x^2}{2t}\right)$ is a solution of the diffusion equation. Draw a graph to illustrate the meaning of this solution. [5]

Deliverable 01: Website Plan

Within your groups produce an outline plan for your website. Your plan must be suitable to be given to a web developer with no subject knowledge, therefore you should provide the developer with the structure of the website, the headings and references to where the content or graphics may be found.

Deliverable 02: Introduction and Links Page

The group should complete a fully detailed introductory page for the website, which will link to the individual pages (deliverable 03), as well external sources of information.

You will be marked primarily on the content of this page not the graphic design. However, you will be marked on style in as much as it supports the delivery of the material, i.e. a clear, well laid out page will gain more marks than something that is 'messy' and difficult to follow.

Remember that when you send these files in that will be hosted on another machine therefore any links/references/images within the document should be *independent* of the machine they are loaded onto. This also means that you must include any relevant images etc in the zipped file.

Deliverable 03: Detailed Webpage

Each group member should choose an additional page from the website plan and develop it in more detail.

You will be marked primarily on the content of this page not the graphic design. However, you will be marked on style in as much as it supports the delivery of the material, i.e. a clear, well laid out page will gain more marks than something that is 'messy' and difficult to follow.

Remember that when you send these files in that will be hosted on another machine therefore any links/references/images within the document should be *independent* of the machine they are loaded onto. This also means that you must include any relevant images etc in the zipped file.

Meta tags

Author: Abel, P.; Raine, D.; Scott, J.

Owner: University of Leicester

Title: Interdisciplinary Science Man and Machines Student Document

Classification: PA2015 / Man and Machines

Keywords: Biology; Biophysics; Physics; Problem-Based Learning; Systems; sfsoer; ukoer

Description: Man and Machines covers topics from the fields of biophysics and physiology - you will research in depth the structure and function of some of the systems of the human body from biological, biochemical and physical perspectives.

Language: English

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File Format: DOCX

Version: 1.0

Additional Information

This module pack is the open student version of the teaching material. An expanded module pack for facilitators and additional information can be obtained by contacting the Centre for Interdisciplinary Science at the University of Leicester. http://www.le.ac.uk/iscience

This pack is the Version 1.0 release of the module.