Science Literacy and Scientific Boundary Questions—Schedule

Wesley J. Wildman — Boston University — 2010-2011 — STH TT871

Description

This course is an introduction to historic and recent scientific theories to the depth needed for reading with understanding most literature in the philosophy and history of science, in religion and science, and in some basic science journals. Another aim of this class is to identify "boundary questions" in the science discussed and to point out how these questions have inspired and influence work in philosophy and religion.

This is not a "popular science" or "science for humanities" course. Literacy in certain disciplines is the goal and, to attain it, the competency required far exceeds that of popular science. For example, a significant amount of mathematics is needed to grasp a large swathe of literature in the philosophy of physics, and most philosophy of biology presumes a detailed knowledge of evolutionary theory.

The pedagogical challenge of this course is to provide this competence in one year available. More familiar methods of science instruction do not work, as they require time-consuming practices such as lab work, memorization, and gaining familiarity with mathematical notation and ideas through repeated calculation. Other methods are adopted in this course and will be discussed, as well as used, in class.

The course is a requirement in the Religion & Science doctoral program. It is the only official course at a Boston Theological Institute (BTI) school that satisfies the science literacy requirement of the BTI's Science and Religion Certificate program. In fact, one semester of the class will satisfy the BTI certificate requirement, but do consult with the instructor well in advance to make sure that you have the necessary background if you plan to take the physics (second) semester of the course.

Requirements

Attendance at both the science lectures (Wednesdays 8-11, STH 115) and the math lectures (Wednesday 7:15-9:25, STH 115) is required for students taking the full year, such as those in the SPR program. Other students may take just the biology section in the Fall. Students wanting to take just the physics section in the Spring must attend the math section in the Fall as well, unless attendance is waived by the instructor. In addition:

- You do not need to purchase texts for this course.The instructors will provide texts where necessary, as well as extensive lecture notes. Reading consists in carefully studying these texts and lecture notes. Aritcles or short books may be assigned to prepare for a segment.
- Each student must have email and web access. This is provided free of charge for registered Boston University students. Documents are shared over email and there is a web site in support of the course under http://blackboard.bu.edu/.
- CD-ROM-based science learning programs may also be required and are available for students to use as needed. Each student should have access to a CD-ROM drive and a computer capable of running these programs. Detailed requirements will be discussed in class.

A grade for the course is assigned on the basis of:

- passing end-of-segment oral examinations with the instructors (see below for details);
- attendance at lectures and tutorials; and
- successful completion of periodic homework assignments.

Note: Incompletes are not given, by STH policy, except under extraordinary circumstances. Speak to Prof. Wildman about your extraordinary situation as soon as possible. Do not leave it to the last minute to ask. Also, remember that the STH Registrar has paperwork requirements.

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Instructors

The instructor for most of the biological sciences section will be Erica Harris (PhD candidate in Behavioral Neuroscience, Boston University School of Medicine), with lectures on physics and chemistry material from Prof. Wildman. The instructor for the physics section will be Prof. Wildman. Prof. Wildman will be teaching the Mathematics section all year. He will also be handling boundary issues throughout the year in all sections of the course.

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Specific Introduction to the Biological Sciences Semester

<u>Course Description</u>

This course is about learning to read and understand biology-related literature in the Philosophy of Biology, the History of Science, the Scientific Study of Religion, and Religion & Science. This scientific literature stems from articles published in professional, peer-reviewed journals by experts in these fields. Some biological scientists and neuroscientists are taking a keen interest in the scientific study of religion and are looking for ways to collaborate with philosophers, religious scholars, and theologians to apply their tools and techniques to understand religion. As a result, you will need to obtain a working knowledge of the broad biological, chemical, and even neurobiological and neurochemical processes and terms that are used to apply this information to your current studies in science, philosophy, and religion.

In order to make this class meaningful and practical, we will focus on the perspective of Behavioral Neuroscience (BN) – understanding the biology behind our behavior. The bottom line is that we take our brains everywhere we go, and everything we do involves our brains. It is impossible to dissociate the brain from any behavior or action. In particular, we are interested in learning more about how neurocognitive and neurobiological theories can explain religion, or at least accessible aspects of religious beliefs, behaviors, and experiences.

Behavioral Neuroscience (BN) is a broad, multi-disciplined field, embracing cognitive psychology, evolutionary theory, psychiatry, neurobiology, biology, and human development. In BN, we want to understand 'What happens to the brain when behavior is not normal?' 'What happens when our brain suffers some sort of insult and produces new behavior?' 'Is the behavior now a permanent, neurological change such as an aphasia resulting from a stroke?' Or, 'Could it be the result of a nutritional deficiency such as a lack of thyroid or B12 that can produce a temporary dementia?' 'What are the larger implications regarding therapies and treatments for people suffering from these problems?' 'How can their quality of life be improved without always resorting to drug therapies?' 'Is it possible that religion could be incorporated to solve some of these problems?' 'What neuroethics issues are involved?' The latter two questions exemplify the types of boundary questions that we will consider as appropriate.

To accomplish these goals, the class has been divided into four sections. In the first section, we will review the basics of physics, general chemistry, and biology. In the second section, we will learn what a neuron is and how neurons communicate via neurotransmission. We will then discover how these basic functional units combine in neuroanatomy, which will help us grasp the functions of the various areas of the brain. The third section will focus mainly on a case study involving Parkinson's Disease (PD), a neurodegenerative movement disorder. We will explore two of the most important non-motor symptoms of PD: executive cognitive dysfunction and personality changes. When we discuss executive cognitive dysfunction, we will review the concept of the Self so that we can begin to understand how the Self can break down in disease. This naturally leads us to a discussion of personality changes in PD. Neurologists report that neurological patients may exhibit a loss or a gain in religious thoughts, feelings, and behaviors. We will ask how this applies to patients with PD. We conclude the course by discussing evolutionary theory and applying evolutionary theories to religion.

It is our hope that this course will give you another perspective – thinking about clinical and neurological populations – with which to approach your specific field of study, and that it will equip you with the tools to comfortably read the scientific literature. By the end of the course, you should have a solid grounding in the underlying biological, chemical, and neurobiological mechanisms of behavior in addition to the neuroanatomic functions of these behaviors, and you should be able to apply these concepts in novel ways to religion. We will attempt to do this by providing you with exercises that will get you to think in new and creative ways.

What are important components of gaining "literacy" in Behavioral Neuroscience?

1. As mentioned above, the field of BN is broad. You need to learn how to navigate the maze of contemporary scientific literature, pick out the pieces that are applicable to study, and decide what is 'good science.' This will make you a critical reader of the literature.
2. You need to learn how to use Internet databases that contain biological information**.**
3. You need to practice dialogue skills for interacting with research scientists by providing class presentations.
4. You need to learn about cutting edge methods and directions in biology/neurology and apply these to the field of religion.

Readings

1) Various handouts and research articles will be available online and handed out in class
2) Textbook: Scott Freeman *Biological Science* (2002); http:/wps.prenhall.com/esm_freeman_biosci_1; copies can be borrowed from Dr. Wildman so there is no need to purchase your own copy
3) Whatever you might find of interest that pertains to the class

Please complete all readings prior to the class session in which they are assigned. Keep in mind that you may have to return to readings, perhaps several times, as you absorb lecture material and prepare for exams.

Format of Class Sessions

We will have a lecture for the first half of the class and then a brief 15 minute break. A portion of the second half of some classes will consist of student presentations. Students may be presenting on class readings at any time. You will be tested on the material from the class presentations so make sure that you help your classmates understand the material that you present. Your materials are their study guides for exams.

Class Attendance

It's expected, so please come. If you have a conflict, please make sure to alert Dr. Wildman or Erica as soon as possible. Significant amounts of missed class time will result in a reduction of your grade.

Examinations

There will be two one-hour oral examinations, one at mid-term and one at the end of term. Examinations may be retaken repeatedly without penalty to improve your grade; they are intended to be learning experiences.

Advice on Studying for Exams: All exams will be presented orally for Dr. Wildman and Erica. 'Why do we have oral exams?' you may ask? Oral exams are the best test of whether you have grasped the materials and organized them coherently. You will basically teach us the material that you have learned. Therefore, we suggest that you practice 'teaching' the material to your friends, or anyone who will listen.

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Practice drawing diagrams on paper or a whiteboard and think about how to organize the information in the form of charts, tables, etc. This will give you the opportunity to focus our attention on the board as opposed to 'all eyes on you'.

Expectations

1. Have fun!
2. Participate
3. Show up for class
4. Complete assignments
5. Pass exams

Grade Components

Oral Examinations (40%)
Presentations (40%)
Attendance and Participation (20%)

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Course Schedule for Biology Semester

The course is divided into 4 sections. Please see below for what we'll be delving into each week:

Week/Date	Topics of Interest	Assigned Readings	Homework or Presentation
Section 1: Basic Physics, Chemistry and Biology			
1: Sep 8	-Introduction to course - Setting up goals for the class/semester -Introduction to quantum chemistry, periodic table; housekeeping discussions of pedagogical philosophy for the biology section	None	
2: Sep 15	-General Chemistry (atoms, bonds, molecules) -Introduction to Chemical Transmission – Neurotransmitters (NTM)	1) Freeman Chp. 2: The atoms and molecules of the Ancient world	
3: Sep 22	-Origin of organic molecules and life on Earth -From biochemistry to cell biology (lipids, proteins) -Processes of cell division (mitosis and meiosis); -Introduction to energy and metabolism -Introduction to Behavioral Neuroscience (BN) research methods	1) Freeman Chp. 3: Macromolecules and the RNA World 2) Freeman Chp. 4: Members and the first cells 3) Freeman Chp. 5: Cell structure and function 4) Freeman Chp. 8: Cell division 5) Freeman Chp. 9: Meiosis	Sign up for presentation of organelle structures
Section 2: Introduction to the Brain			
4: Sep 29	Neural Transmission – Part I	1) Freeman Chp. 42: Electrical signals in animals	Sign up for Journal Presentation
5: Oct 6	Neural Transmission – Part II		
6: Oct 13	Neuroanatomy – Part I	1) Freeman Chp. 18: Introduction to	

		Development 2) Freeman Chp. 19: Early Development	
7: Oct 20	Neuroanatomy – Part II		
Section 3: A Case Study on Parkinson's Disease and Associated Neuropsychological Deficits			
8: Oct 27	Introduction to Parkinson's disease	See assigned readings	Sign up for Neurological Disease Presentation
9: Nov 3	Executive Cognitive Deficits in Parkinson's disease	See assigned readings	Sign up for presentation about Frontal Lobe Tests
10: Nov 10	Personality in Parkinson's disease	See assigned readings	Sign up for Personality in PD presentation
Section 4: Evolutionary Approaches and Neurocognitive Theories of Religion			
11: Nov 17	Introduction to Evolutionary Theory – Part I	1) Freeman Chp. 21: Darwinism and the Evidence for Evolution 2) Freeman Chp. 22: Evolutionary Processes 3) Freeman Chp. 23: Speciation 4) Freeman Chp. 24: The History of Life	
12: Nov 24	**No Class – Fall Recess – Thanksgiving**		
13: Dec 1	Introduction to Evolutionary Theory – Part II: Evolutionary Theories of Religion from the Perspective of Cognitive Neuroscience	See assigned readings	Sign up for Action Script Generation Presentation
14: Dec 8	Neurologic Constraints on Evolutionary Theories of Religion		

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Reading List for Biology Semester

Week 8: Introduction to Parkinson's disease

Chaudhuri, K. R., Healy, D. G., & Schapira, A. H. V. (2005). Non-motor symptoms of Parkinson's disease: Diagnosis and management. *The Lancet Neurology, 5*(3), 235-245.

Jankovic, J. (2008). Parkinson's disease: Clinical features and diagnosis. *Journal of Neurology, Neurosurgery and Psychiatry, 79*, 368-376.

Langston, J. W., Ballard, P., Tetrud, J. W., & Irwin, I. (1983). Chronic Parkinsonism in humans due to a product of Meperidine-analog synthesis. *Science, 219*(4587), 979-980.

Parkinson, J. (2002). An essay on the shaking palsy. *Journal of Neuropsychiatry and Clinical Neuroscience, 14*(2), 223-236.

Additional Readings of Interest

Gerstenbrand, F., & Karamat, E. (1999). Adolf Hitler's Parkinson's disease and an attempt to analyze his personality structure. *European Journal of Neurology, 6*(2), 121-127.

Jones, J. (2004). Great shakes: Famous people with Parkinson's disease. *Southern Medical Journal,* 97(12), 1186-1189.

Week 9: Executive Cognitive Deficits in Parkinson's disease

Barkeley, R. A. (2001). The executive functions and self-regulation: An evolutionary neuropsychological perspective. *Neuropsychology Review, 11*(1), 1-29.

Ettlin, T., & Kischka, U. (1999). Beside frontal lobe testing: "The frontal lobe score." In B. L. Miller & J. L. Cummings (Eds.), *The human frontal lobes: Functions and disorders* (pp. 233-246). New York: The Guilford Press.

Week 10: Personality in Parkinson's disease

McNamara, P., Durso, R., & Harris, E. (2007). '"Machiavellianism" and frontal dysfunction: Evidence from Parkinson's disease.' *Cognitive Neuropsychiatry, 12*(4), 285-300.

Stuss, D. T., Glow, C. A., & Hetherington, C. R. (1992). "No longer Gage": Frontal lobe dysfunction and emotional changes. *Journal of Consulting and Clinical Psychology, 60*(3), 349-359.

You will be assigned additional readings in class.

Week 13: Introduction to Evolutionary Theory – Part II: Evolutionary Theories of Religion from the Perspective of Cognitive Neuroscience

Banyas, C. A. (1999). Evolution and phylogenetic history of the frontal lobes. ." In B. L. Miller & J. L. Cummings (Eds.), *The human frontal lobes: Functions and disorders* (pp. 83-106). New York: The Guilford Press.

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Spring 2011 Physics Schedule

Segment P1: Electromagnetism [Prof. Wildman]

Week 1 Jan 20	Basic laws of electrostatics (Coulomb, Ampere, and Faraday)
Week 2 Jan 27	Maxwell's equations (including theorems of Gauss and Stokes)

Oral Examination of Material in Segment P1

Segment P2: Special Theory of Relativity [Prof. Wildman]

Week 3 Feb 3	Conceptual Basics (classical mechanics; Galilean transformation; inertial frames of reference; motivation for a new mechanics; Lorentz transformation)
Week 4 Feb 10	Relativistic Mechanics (postulates of STR; relativity of simultaneity; length contraction; time dilation; addition of velocities; twin paradox; experimental evidence)
Week 5 Feb 17	Relativistic Dynamics (mass-energy equivalence), Electrodynamics and relativity (Maxwell's equations in tensor notation)

Oral Examination of Material in Segment P2

Segment P3: General Theory of Relativity [Prof. Wildman]

Week 6 Feb 24	Conceptual Basics (theory of gravity or general theory of relativity?), Space-Time Tells Matter-Energy how to Move (geometric point of view; the equation of geodesic deviation; Riemann tensor; analogy with electromagnetism and Newtonian physics; calculating Riemann components)
Week 7 Mar 3	Matter-Energy Tells Space-Time how to Curve (calculating with equation of geodesic deviation; Einstein tensor; stress-energy tensor)
Week 8 Mar 10	Einstein's Field Equations (approximation methods for solving Einstein's field equations for entire universe; the closed universe; cosmological constant; other applications of GTR)
Mar 17	No Class: Spring Recess

Segment P4: Cosmology [Prof. Wildman]

Week 9 Mar 24	Early Cosmology (ancient and medieval concepts, planetary system debates, Galileo, Kepler)
Week 10	Big Bang cosmology (basic observations and theoretical model), Quantum cosmologies

Mar 31	(competing models of the early universe)

Oral Examination of Material in Segments P3, P4

Segment P5: Quantum Mechanics [Prof. Wildman]

Week 12 Apr 7	Basic Experiments and Theoretical Moves (Plank's postulate; photoelectric effect; Compton effect; atomic spectra; DeBroglie's postulate; scattering experiments; low-intensity polarization; double-slit experiment; uncertainty principle)
Week 13 Apr 14	Formalism (Stern-Gerlach experiment; prediction versus explanation; wave functions; states, properties, and measurements; quantum electrodynamics)
Apr 21	No Class: Substitute Monday Schedule
Week 14 Apr 28	Non-Locality (Bohr versus Einstein; Einstein-Podolsky-Rosen thought experiment; Bell's inequalities)
Week 15 May 5	Interpretations of Formalism (basic problems from the measurement problem to quantum chaos; Copenhagen "interpretation"; theories of measurement from DeBroglie, Bohm, and Popper to von Neumann, Wigner, and Everett)

Oral Examination of Material in Segment P5

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Fall 2010 Mathematics Schedule

Segment M1: One-Dimensional Calculus [Prof. Wildman]

Week 1 Sep 9	Introduction (mathematical notation; number system; functions; continuity)
Week 2 Sep 16	Differentiation I (from first principles; geometrical interpretation of the derivative; circles, sine and cosine functions)
Week 3 Sep 23	Differentiation II (basic derivatives; basic rules of differentiation; differential equations)
Week 4 Sep 30	Integration I (from first principles; geometric interpretation of integral; sine and cosine functions revisited)
Week 5 Oct 7	Integration II (definite versus indefinite integrals; basic integration rules and techniques)
Week 6 Oct 14	Fundamental Theorem of Calculus (relation between areas under curves and anti-derivatives)

Oral Examination of Material in Segment M1

Segment M2: Vector Spaces and Basic Linear Algebra [Prof. Wildman]

Week 7 Oct 21	Vectors (geometrical interpretation; basic operations; length; angle), Bases (linear combinations; linear independence; dimensionality)
Week 8 Oct 28	Vector Spaces (definition; functions)

Segment M3: Vector Calculus (for Physics Segment P1) [Prof. Wildman]

Week 9 Nov 4	Generalizing the Derivative (directional derivative; gradient; divergence; curl; notation)
Week 10 Nov 11	Generalizing the Integral (path integral; surface integral; volume integral)
Week 11 Nov 18	Amazing Theorems (divergence theorem; Stoke's theorem)
Nov 25	No Class: Thanksgiving Recess
Dec 2	Vector Calculus Applications (electrostatics)

Dec 9	Review and practice

Oral Examination of Material in Segments M2, M3

Spring 2011 Mathematics Schedule

Segment M3 (continued): Vector Calculus (for Physics Segment P1) [Prof. Wildman]

Week 1 Jan 20	Vector Calculus Applications, continued (electrostatics)

Segment M4: More Linear Algebra (for Physics Segment P2) [Prof. Wildman]

Week 2 Jan 27	Basis Change (coordinate systems; bases; basis change functions)
Week 3 Feb 3	Matrices (definition; matrix algebra; solving simple simultaneous equations; basis change functions represented as matrices; Galilean transformation; Lorentz transformation)

Segment M5: Tensor Calculus (for Physics Segments P3, P4) [Prof. Wildman]

Week 4 Feb 10	Understanding the Metric Tensor and the Polarization Tensor (building physical intuition for tensors; creating mathematical notation for describing the physics)
Week 5 Feb 17	Tensors in General Form (multi-linear functions; linear functionals; contravariant and covariant indices; partial derivatives)
Week 6 Feb 24	Examples (electromagnetic tensor; Riemann curvature tensor; stress-energy tensor)
Week 7 Mar 3	Breaking Down the Einstein Field Equations (Riemann curvature tensor; Ricci tensor; connections; Christoffel symbols; Einstein tensor)

Segment M6: Hilbert Spaces (for Physics Segment P5) [Prof. Wildman]

Week 8 Mar 10	Hilbert Spaces (definition; bases; orthonormal bases; basis change)
Mar 17	No Class: Spring Recess
Week 9 Mar 24	Functions on Hilbert Spaces (functions; operators), Application to Quantum Mechanics (wave functions, observables, and measurements)

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Segment M7: Complex Analysis (for Physics Segment P5) [Prof. Wildman]

Week 10 Mar 31	Complex Number System (numbers, operations, converting between polar and Cartesian coordinates)
Week 11 Apr 7	Complex Functions (examples of complex functions, complex exponential function, application to wave functions, wave equation)

Segment M8: Chaos Theory [Prof. Wildman]

Week 12 Apr 14	The Logistic Mapping (understanding iteration; exploring bifurcation diagram using computer software; identifying regimes)
Apr 21	No Class: Substitute Monday Schedule
Week 13 Apr 28	Chaos (definitions; controversies; philosophical issues from modeling to meaning)
May 5	Review and practice

Science Literacy and Scientific Boundary Questions—Examinations

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Examination Content, Described by means of Sample Questions

These questions merely indicate the content of oral examinations. Exams are not limited to these questions. In general, and throughout the exams where appropriate, be prepared to speak about the relevance of the scientific material to philosophical, ethics, metaphysical, and theological questions (we call these "boundary issues").

Examination of Biology Segments B1, B2, B3: Chemistry and Biochemsitry

What are fermions (leptons and quarks), bosons? What do they do, what do they make, how do they interact?

Explain why the periodic table arranged the way it is.

What is electron configuration for a given element? valence number? group? Calculate chemical formula for simple ionically bonded compounds based on valence numbers. "Read" a symbolic chemical structure of an organic molecule.

Desribe the various types of chemical bonds and their relative strengths (ionic bonds, covalent bonds, hydrogen bonds, Van der Waal's forces)

How does a chemical reaction work? What role does a catalyst play in a chemical reaction? What is a favorable reaction? How do you run reactions in unfavorable directions? Draw reaction energy diagrams.

Describe the four main macromolecules, their monomers, differences in their structure.

Lipids: triglycerides, phospholipids, cholesterol. What is hydrophobicity? Lipid bilayer?
Carbohydrates: 6-member glucose ring, polysaccharides
Proteins: amino acid structure, types of amino acid side chains, peptide bond formation
Nucleic acids: nucleotide structure, four nucleotides, purines vs. pyrimidines

Describe the role of hydrogen bonding in formation of protein secondary structure (alpha helix, beta sheet), DNA double helix, DNA:RNA complexes during transcription and RNA-RNA complexes during translation.

How did the Miller-Urey experiments try to recreate the origin of biological molecules on young Earth?

Describe the role of protein enzymes as biological catalysts. Give an example of a chemical reaction facilitated by enzymatic activity.

Describe the structure and function of following cellular components: plasma membrane, cell wall, cytoplasm, cytoskeleton, nucleus, rough endoplasmic reticulum, smooth endoplasmic reticulum, Golgi, mitochondria, chloroplast. What mitochondrial processes lead to ATP production?

What are exocytosis, endocytosis and phagocytosis? What is the connection between these processes and movement of membrane vesicles within a cell? What is endosymbiotic hypothesis?

Draw a schematic and name the phases of the cell cycle. Where does DNA replication occur? What important checkpoint control must happen during the G1 and G2 gap phases to ensure smooth progression towards mitosis? Describe the processes that occur during mitosis (chromosomal condensation, disassembly of nuclear envelope, chromosomal alignment, chromosomal separation and physical separation of the daughter cells). What cytoskeletal structures pull chromosomes apart?

What experiments demonstrated the role of DNA as hereditary material? How is DNA organized in chromosomes? Why DNA replication is called “semiconservative”? Definition of a gene and the concept of gene expression. What is genetic code? Transcription; mRNA processing; introns and exons. tRNA, rRNA, ribosome and the “decoding” process; catalytic activity of RNA.

Examination of Biology Segments B4, B5: Cell Biology and Evolutionary Biology

Describe the types of cell. Describe the various parts of the cell (cell membrane, nucleus, mitochondrian, chloroplast, vesicular network, cytoskeleton) and give details about processes within each.

Distinguish between meiosis and mitosis. Outline the steps in each and the final outcome regarding the amount of cellular DNA present.

Describe cells in a functional context (either the immune system of the nervous system, depending on what was covered in class).

Summarize the work of Gregor Mendel. What two main principles of genetics were derived from his work (Independent Assortment and Segregation)? What is the molecular biological basis for these principles? What is an allele?

In mice there are two separate alleles for coat color and hair length. The dominant alleles are gray coat with short hair and the recessive alleles are tan coat with long hair. Work out a cross between a homozygous dominant mouse with a homozygous recessive mouse in the P generation and predict the allelic distribution in the F1 and F2 generations.

Summarize Darwin’s theory of natural selection. What evidence did Darwin adduce in support of it? What were its major flaws? What is the Modern Synthesis?

How does speciation occur? What are the factors relevant to population and evolutionary change?

Examination of Mathematics Segments M1: One-Dimensional Calculus

What is a function? Continuous function? Graph of a function? Tangent to a graph? Slope of a tangent?

How do the sine and cosine functions relate to the geometry of a circle?

Define the derivative (from first principles). Describe the geometric meaning of a derivative.

What are basic rules of differentiation? Basic derivatives? Differential equations?

Define the integral (from first principles). Describe the geometric meaning of an integral. Distinguish definite from indefinite integrals.

What are basic rules of integration? Basic integrals? Basic integration techniques?

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What is an anti-derivative? State the fundamental theorem of calculus? Describe the relation between anti-derivatives and areas under curves.

Examination of Mathematics Segments M2, M3: Vector Calculus

What is a vector space? linear combination? linear dependence and independence? basis?

How do we define a metric on a vector space? Explain "a metric is a bi-linear, positive-definite quadratic form." Examples of metrics on R^2, including graphs of length-1 vectors in Euclidean and Lorentzian metrics.

How do we use a metric to speak of length of vectors and angle between vectors? What is orthonormal basis? coordinate system? How do we represent the same vectors in more than one coordinate system?

What is scalar (dot) product? vector (cross) product? linearity of an operation? test for orthogonality? right-hand rule? geometric and coordinate representation of dot product and cross product?

What are examples of functions with a variety of vector-space domains and ranges? vector fields and scalar fields? component scalar fields of a vector field?

What is directional derivative? partial derivative relative to a basis?

What is gradient? del? divergence? curl?

What is integral over a curve? a surface? a volume?

What is flux? circulation?

What is Gauss's theorem (divergence theorem)? Stokes' Theorem?

Examination of Physics Segments P1: Electromagnetism

State Maxwell's equations in differential and integral form. Show how to derive the integral from the differential form, and *vice versa*.

Explain the connection between Maxwell's equations and the basic results of electrostatics. Derive Coulomb's law from Maxwell I and Ampere's Law from Maxwell II.

Write down the field equation for Electromagnetic radiation. (Bonus: derive it from Maxwell's equations!) Explain the velocity of electromagnetic radiation from the field equation.

How do Maxwell's equations establish the unification of light and electromagnetism? What is the significance of this result?

Examination of Physics Segments P2: Special Theory of Relativity

What is an inertial frame of reference? Principle of relativity? Galilean transformation?

State the postulates of STR. Describe the Lorentz transformation and its significance.

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State the mechanical consequences of STR: relativity of simultaneity (via thought experiment), length contraction and time dilation (write up formulas), addition of velocities (write up formula).

State the dynamical consequences of STR: mass-energy equivalence (explain the energy triangle).

Describe experiments confirming STR.

What is a space-time diagram? Use one to explain the Lorentz Metric versus the Euclidean metric. Use one to explain the twin paradox.

What is the philosophical significance of STR for understanding space and time?

Examination of Physics Segments P3, P4: General Theory of Relativity and Cosmology

1. Tensors
Tensor in general form
Coordinate language verus "object" language
Einstein summation convention
Examples of tensors (metric tensor, Riemann)
Differentiation of tensors
Parallel transport, geodesics, and curvature

2. General Theory of Relativity
Why the name GTR rather than "theory of gravity"?
Geometric point of view (unconstained motion defines a geodesic in a curved space)
Global versus local point of view
Equation of geodesic deviation for a sphere (derive and interpret)
Equation of geodesic deviation generally (state and interpret)
Riemann curvature tensor (calculate Reimann components near the earth and inside the earth)
Definition of Einstein Tensor and its constitutive tensors
Einstein's field equations (state and interpret)

3. Big-Bang Cosmology
Basic assumptions: homogeneity and isotropy
meaning of t,t component of field equations when density is constant [$(a'')^2=(8\pi\rho a^2)/3 -1$]
interpretation as dynamic universe; Einstein's reaction (introduced cosmological constant)
Big-Bang Cosmology
Evidence (Hubble, CBR, nuclear abundance, dark night sky,...)
Narrative of early universe, including connections between high-energy particle physics and cosmology
Inflation used to explain problems (such as flatness of universe and variations in CBR)

4. Quantum Cosmologies
The overriding purpose of quantum cosmologies
The connection between high-energy particle physics and quantum cosmologies
Various quantum cosmologies—qualitatively describe and compare
The metaphysical significance of quantum cosmologies

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Examination of Physics Segments P5: Quantum Machanics

1. Early discoveries
1.1 Energy quantization of radiation
Plank (1901) Black Body
Einstein (1905) Photoelectric Effect
Bohr (1913) Atomic Spectra
Compton (1923) Scattering Xrays from foil
1.2 Interference effects of particles
DeBroglie's (1924) postulate of wavelength tied to momentum
Davisson-Germer (1927) and Thompson (1928) crystal scattering and transmission of electrons
1.3 Double-slit experiment (illustrates Heisenberg Uncertainty Principle)
1.4 Stern-Gerlach experiment (illustrates probabilities nature of measurement outcomes)

2. Formalism
2.1 Mathematical interpretation of systems, states, observables, measurement
2.2 von Neumann's Hilbert Space approach
2.3 Born's Projection Postulate
2.4 Schrödinger's Equation

3. Non-locality
3.1 Einstein-Podolsky-Rosen thought experiment (1935): locality entails violation of uncertainty principle, which implies incompleteness of quantum mechanics
3.2 Bell's inequalities: locality entails that statistics from experiments on correlated particles pairs should conform to specific inequalities (but Aspect's experiments show they do not, thus demonstrating non-locality)
3.3 Non-locality and faster-than-light information transfer

4. Philosophical Interpretation
4.1 Three levels of interpretation
Correspondence rules and associated principles connecting formalism to observable phenomena
Creating conceptually unifying, semi-pictorial models
Adjustments to theory on the basis of appealing models
4.2 Major interpretations
Standard (Copenhagen) interpretation (distinguish from Bohr)
Many Worlds and Many Minds interpretations
Hidden Variables interpretations (esp. Bohm)
Continuous Spontaneous Localization theories
4.3 Significance for theology (optional)
Freedom versus determinism
Locus for natural-law-conforming action of divine being
Entanglement and unity of divine creation