Syllabus for CCVX Preliminary Examination in Physics

This document sets out the general learning outcomes of the programme for the Physics Preliminary Examination of the Centrale Commissies Voortentamen (Central Committees for Preliminary Examinations), starting with the November 2017 Preliminary Examination.

This specification is based on the learning outcomes of the programme for the Central Examination and School Examination as held for Physics in VWO secondary schools from May 2016. The Preliminary Examination tests knowledge of the syllabus for both the Central Examination and the School Examination.

As long as this list is on the site of the CCVX, this list is automatically up to date.

If the syllabus for the Preliminary Examination differs from that of the current programme for the Central Examination or School Examination, the CCVX programme always applies.

A Binas booklet may be used during the preliminary-exam. Many of the formulas that belong to the programme can be found in that booklet. But if a formula that is part of the programme does not occur in Binas, the candidate must know that formula by heart.

Date: 15 August 2025

1. The CCVX Preliminary Examination in Physics

The Preliminary Examination is a written examination.
It lasts three hours.

The syllabus comprises the following domains:
- Domain A Skills
- Domain B Waves
- Domain C Motion and Interaction
- Domain D Charges and Fields
- Domain E Radiation and Matter
- Domain F The Quantum World and Relativity
- Domain H Laws of Nature and Models
- Domain I Research and Design

The Physics Preliminary Examination relates to Domains B-I in conjunction with the skills in Domain A, except for those aspects that do not by their nature lend themselves to written examination, including skills that expressly require a computer workstation.

For examples of examination questions see the specimen examinations on the CCVX website (www.ccvx.nl) and past written examinations. The type of questions may differ somewhat from those based on the Dutch “College voor Toetsing en Examens” (CvTE) current interpretation of the learning outcomes, as the CCVX preliminary examinations place more emphasis on calculation and less emphasis on language proficiency and reading skills.

The following specification of the syllabus for the CCVX Physics Preliminary Examination lists:
- the domains and subdomains being tested
- a single general learning outcome for each subdomain
- the general learning outcomes, supplemented by specimen contexts and specific concepts.

The specimen contexts are intended as minimum requirements; they are certainly not designed to exclude other possible specimen contexts.

2. The Syllabus for the Preliminary Examination

Domain A - Skills

The skills are divided into three categories:

Subdomains A1-A4:	General Skills
Subdomains A5-A9:	Scientific, Mathematical and Technical Skills
Subdomains A10-A15:	Specific Physics Skills

Subdomain A1 - Using Information Skills
The candidate is able is search for, judge, select and process information systematically.

Subdomain A2 - Communication
The candidate is able to communicate effectively on subjects in the respective area in writing, verbally and digitally in the public domain.

Subdomain A3 - Reflecting on Learning
The candidate is able to reflect on his interests, motivation and learning process in acquiring subject knowledge and technical skills.

Subdomain A4 - Studies and Professions
The candidate is able to describe how scientific knowledge is used in studies and professions and based on that, among other things, to put his interest in studies and professions into words.

Subdomain A5 - Research
The candidate is able in particular contexts to analyse problems using relevant concepts and theory, translate them into specific research, conduct that research and draw conclusions from the results, using consistent arguments and relevant arithmetical and mathematical skills.

Specification:
The candidate is able, using consistent arguments and relevant arithmetical and mathematical skills, to:

1. recognize and specify a scientific problem
2. express a scientific problem as one or more research questions
3. identify relationships between a research question and scientific knowledge
4. formulate a hypothesis and expectations for a research question
5. draw up a work plan for a scientific study to answer one or more research questions
6. carry out relevant observations and collect measuring data to answer a research question
7. process measuring data and present them in a way that helps to answer a research question
8. from data collected in a study draw conclusions relating to that study's research question(s)
9. evaluate how a study was conducted and its conclusions, using the concepts of precision, reliability and validity
10. present a scientific study.
11. explain that, in addition to an experimental research approach, other research approaches are also possible;
12. indicate the nature of research results, using the concepts of uncertainty and probability.

Subdomain A6 - Design
The candidate is able in particular contexts to prepare, implement, test and evaluate a technical design based on a set problem, using relevant concepts, theory and skills and valid, consistent arguments.

Specification:
The candidate is able, using relevant concepts, theory and skills and valid, consistent arguments, to:

1. describe a technical design problem
2. breaking down a design problem into a number of separately solvable sub-problems (tasks, properties)
3. draw up a schedule of requirements and preferences: constraints, requirements, priorities and preferences
4. identify relationships between scientific knowledge and the functions and properties of a design
5. produce several versions of the functions and properties of a design
6. put forward a reasoned design proposal for a design
7. create a prototype of a design
8. test and evaluate a design process and product, taking the schedule of requirements into consideration
9. put forward proposals to improve a design
10. present a design process and product in an appropriate manner.

Subdomain A7 - Modelling
The candidate is able in particular contexts to analyse a relevant problem, reduce it to a workable problem, translate it into a model, generate and interpret model results, and verify and assess the model, using consistent arguments and relevant arithmetical and mathematical skills.

Specification:
The candidate is able, using consistent arguments and relevant arithmetical and mathematical skills, to:

1. specify a natural scientific phenomenon with the aim of describing, explaining, or predicting it;
2. simplify a natural scientific phenomenon and identify its essential characteristics;
3. identify the similarities and differences between a model and reality with the aim of determining the suitability and scope of the model;
4. assess the extent to which a model is appropriate for the purpose for which it is used;
5. select a suitable physical, schematic, or mathematical representation for a model and quantify it where necessary;
6. create or adjust an adequate model;
7. use a model to describe, explain, and/or predict the properties of a natural scientific phenomenon;
8. make proposals for the improvement and/or expansion of a model;
9. present the creation, structure, or use of a model.

Subdomain A8 - Scientific Instruments
The candidate is able in particular contexts to use scientifically relevant instruments, paying attention where necessary to risks and safety, namely instruments for data collection and processing, scientific language, scientific conventions, symbols, formulas and arithmetical calculations.

Specification:
The candidate is able to:

1. obtain and select information from written, oral and audiovisual sources, using IT among other things, to:
    - extract data from graphs, tables, drawings, simulations, charts and diagrams
    - look up parameters, units, symbols, formulas and data in appropriate tables
2. analyse information, data and measurements, reproduce and organize them in graphs, drawings, charts, diagrams and tables, using IT among other things

3. explain what is meant by the significance of measured values and give the results of calculations to the correct number of significant digits:
    - when adding and subtracting, giving the result to as many decimal places as the given measured value with the smallest number of decimal places
    - when dividing and multiplying, giving the result to as many significant digits as the given measured value with the smallest number of significant digits
    - when using logarithms, giving the answer to as many decimal places as the measured value has significant digits
    - integers obtained by counting discrete objects are not covered by the rules for significant digits (this also applies to mathematical constants and monetary amounts)
4. indicate what techniques and apparatus are used to measure the most important scientific parameters
5. handle materials, instruments, organisms and the environment responsibly.

Subdomain A9 - Evaluation and Judgment
The candidate is able in particular contexts to give a reasoned judgment of a situation in nature or a technical application, distinguishing between scientific arguments, normative social considerations and personal views.

Specification:
The candidate is able to:
1. give a reasoned judgment of a situation in which scientific knowledge plays an important role, or make a reasoned choice between alternatives in questions of a scientific nature
2. distinguish between scientific arguments, normative social considerations and personal views
3. cite sources for facts
4. assess the reliability of information and determine its value as regards answering the respective question.

Subdomain A10 - Developing and Using Knowledge
The candidate is able in particular contexts to analyse how scientific and technological knowledge is developed and applied.

Subdomain A11 - Technical and Instrumental Skills
The candidate is able to handle the materials, instruments, apparatus and IT applications relevant to physics responsibly.

Specification:
The candidate is able to:
1. use knowledge of materials, instruments and apparatus in practice to implement experiments and technical designs relating to the subject matter set out in the domains,
    - including the following materials, instruments and apparatus:
      - measuring tape, graduated cylinder, stopwatch and scales
      - tuning fork, tone generator, oscilloscope, Geiger counter
      - force gauge, air track, stroboscope
      - liquid thermometer, spring
      - filters, spectroscope
      - electroscope, power supply, adjustable resistor
2. use knowledge of IT applications to implement experiments and model studies relating to the subject matter set out in the domains,
    - including the following applications:
      - computer with sensors, light gate
      - video measurement, measuring software
      - modelling software
      - software for processing and analysing measurement data.

Subdomain A12 - Arithmetical and Mathematical Skills
The candidate is able to use a number of arithmetical and mathematical skills relevant to physics correctly and as a matter of routine in problem situations specific to physics.
Specification:
The candidate is able to:

1. use basic arithmetical skills
    - calculate ratios, percentages, fractions, powers and roots
    - calculate the circumference and area of a circle, a triangle and a rectangle
    - calculate the surface area of a sphere
    - calculate the surface area of a cylinder
    - calculate the volume of a rectangular solid, a cylinder and a sphere
    - use absolute value
2. use mathematical techniques
    - develop formulas
    - reason in terms of proportions (direct, inverse, quadratic, inverse quadratic)
    - solve linear and second-degree equations
    - solve two linear equations with two unknowns
    - use $\log(x)$, $\ln(x)$, e^{-ax}, e^{ax}, a^x, x^a, $\sin(x)$ and $\cos(x)$
    - in a right-angled triangle, given two sides or given one side and one angle, calculate the other sides and angles using sine, cosine, tangent and Pythagoras' theorem
    - Applying similarity to triangles
    - add and resolve vectors graphically
    - draw graphs for a measurement series,including a trend line
    - write function rules for linear functions, proportional functions (direct, inverse, quadratic, inverse quadratic) and root functions, including a trend line
    - draw graphs using a function rule
    - read diagrams, including logarithmic diagrams, double-logarithmic diagrams and diagrams with axis interruptions
    - interpolate and extrapolate in diagrams and tables
    - differentiate between linear and quadratic functions, power functions, sine functions and cosine functions
    - draw the tangent to a curve and calculate the gradient
    - calculate the area under a curve
    - show relations of the type $y = ax^2$, $y = ax^{-1}$, $y = ax^{-2}$ and $y = ax^{½}$ using coordinate transformation as a straight line through the origin
3. perform calculations with known parameters and relationships, using the correct formulas and units:
    - formulas as listed under the subject-matter subdomains or given in the exam
    - substitute formulas
    - convert, derive, and check units in physics formulas.

Subdomain A13 - Scientific Language
The candidate is able to interpret and produce the specific scientific language and scientific terminology, including formulas, conventions and notations.

Specification:
The candidate can, in formulas as mentioned in the content subdomains or given in the exam:

1. indicate the meaning of the symbols and notations;
2. distinguish between dependent and independent variables, parameters, and constants, depending on the situation;

Subdomain A14 - Scientific Use of a Computer
The candidate is able to use a computer to model and visualize phenomena and processes and to process data.

Specification:
The candidate can:

1. use numerical models in contexts within all subdomains;
    - design a numerical model;
    - convert an existing calculation model into a numerical model;
    - interpret and analyze a numerical model and recognize the underlying physics;
    - supplement an incomplete numerical model;
    - adapt a numerical model to a changed physical situation;
    - evaluate a numerical model based on results, expectations, and (measurement) data
    - taking into account any margins of error in model parameters;
    - recognize the following notations: If..Then.. (Otherwise..) End If, AND, OR, Stop, Sign(), Abs();
    - technical terms: model rule, start value, stop condition, step size, iterative process;
2. using the computer to visualize phenomena and processes, and to process data

Subdomain A15 - Quantifying and Interpreting
The candidate is able to quantify physical parameters and link mathematical expressions to relationships between physical concepts.

Specification:
The candidate is able to:

1. use reasoned estimates for unknown quantities when solving physics problems;
2. using formulas as specified in the subject-specific subdomains or given in the entrance exam:
    - perform calculations with known quantities, using the correct formulas and units, including converting, deriving, and checking units and converting them to SI base units;
    - estimating the order of magnitude of a quantity or result in advance and assessing afterwards to what extent the result of a problem can be correct;
    - interpreting the slope and the area under the graph from a graph based on the quantities on the axes as a physical quantity;
3. in formulas as mentioned in the subject-specific subdomains or given in the exam:
    - indicate the influence of changes in variables on each other;
    - discuss any physical limitations that apply to the applicability of the formula;
    - recognize known mathematical patterns, as mentioned in specification A12.2;
4. recognize differences and similarities in mathematical equations and scientific formulas (structure, number of independent variables, use of units, parameters, and expressing constants in numbers);
5. rewrite a formula to another dependent variable

Domain B - Waves

Assumed to be known:
The candidate is able to:

- design and use a numerical model

The candidate is familiar with:

- a model language for a computer model in model rules or in a graphical representation
- the following phenomena:
  - sound, ultrasound
  - echo
- the following relationships:
  - the relationship between the amplitude of an oscillogram and the sound level of the tone recorded

- the relationship between the frequency of an oscillogram and the pitch of the tone recorded.

Subdomain B1 - Information Transfer
The candidate is able in particular contexts to use the properties of vibrations and waves to analyse and explain such things as information transfer.

Specification:
The candidate is able to:

1. analyse vibration phenomena and represent them graphically
   - using a numerical model, show the relationship between the physical criteria for a harmonic vibration (a force proportional to and in a direction opposite to the displacement) and its mathematical description (sine function and cosine function)
   - concepts: period, reduced phase, phase difference
2. do calculations of the resonance of a mass-spring system
   - concepts: resonant frequency, resonance
3. analyse wave phenomena and represent them graphically
   - apply the fact that sound is a wave phenomenon;
   - concepts: reduced phase, phase difference, travelling wave, propagation speed, speed of sound, echo, speed of light, transverse, longitudinal
4. in the case of a standing wave analyse the relationship between the wavelength and the length of the vibrating medium
   - concepts: node, antinode, fundamental, overtone
   - at least in the following context: musical instruments
5. determine the physical properties (see specifications 1 and 3) of the vibrations and waves from (u,t) and (u,x) diagrams
   - at least in the following context: cardiogram, oscillogram
6. explain how the observed wavelength and frequency of a wave change when the source and receiver move relative to each other.
   - technical term: Doppler effect

The following formulas are included in these specifications:

$$f = \frac{1}{T} \qquad v = f\lambda \qquad \vec{F}_{res} = -C\vec{u} \qquad T = 2\pi\sqrt{\frac{m}{C}} \qquad \Delta\varphi = \frac{\Delta t}{T} \qquad \Delta\varphi = \frac{\Delta x}{\lambda}$$

$$v_{max} = \frac{2\pi A}{T} \qquad u(t) = A\sin(\frac{2\pi}{T}t)$$ not: given u(t) calculate t

$$\ell = n \cdot \tfrac{1}{2}\lambda \quad (n = 1,2,\ldots) \qquad \ell = (2n-1)\cdot \tfrac{1}{4}\lambda \quad (n = 1,2,\ldots)$$

Subdomain B2 - Medical Imaging
The candidate is able to describe the properties of ionising radiation and its effects on humans and the environment. The candidate is also able to describe medical imaging techniques and analyse them in terms of physics principles and explain the diagnostic function of these imaging techniques for health.

Specification:
The candidate is able to:

1. describe the emission, propagation and absorption of electromagnetic radiation
   - concepts: absorption, emission, electromagnetic wave, photon
2. list the various types of ionizing radiation, how they are created and their properties, and the risks of these types of radiation to humans and the environment, and calculate equivalent doses

- calculate and determine radioactivity at a particular point in time from an (N,t) diagram
- write the equation for a nuclear reaction
- concepts: radiation source, radioactive decay, isotope, nucleus, proton, neutron, electron, atomic mass unit, ionising and penetrating power, range, X-radiation, alpha, beta and gamma radiation, cosmic radiation, background radiation, irradiation, contamination, effective whole body dose in relation to radiation protection standards, dosimeter
- at least in the following contexts: nuclear diagnostic medicine, radiation protection

3. solve problems involving half-life or half-depth of penetration
   - concepts: penetration curve, decay curve
   - at least in the following context: medical diagnosis
4. describe medical imaging techniques in terms of their physics background, list the pros and cons of these techniques and on that basis argue which technique should be selected in given situations
   - imaging techniques: X-ray, CT scan, MRI scan, PET scan, ultrasound scan and nuclear diagnostics
   - physics background: half-depth penetration of human tissue, magnetic field and resonance, environmental dependence of relaxation time, annihilation, creation of an electron-positron pair, ultrasonic sound wave, speed of sound in human tissue, absorption, transmission, reflection, tracer.

The following formulas are included in these specifications:

$$E_f = hf \qquad c = \lambda f \qquad A = -\frac{dN}{dt} \qquad A = \frac{\ln 2}{t_{½}} N$$

$$D = \frac{E}{m} \qquad H = w_R D \qquad A = Z + N$$

$$A(t) = A(0) \cdot ½^{\frac{t}{t_{½}}} \qquad N(t) = N(0) \cdot ½^{\frac{t}{t_{½}}} \qquad I(x) = I(0) \cdot ½^{\frac{x}{d_{½}}}$$

Domain C - Motion and Interaction

Assumed to be known:
The candidate is able to:

- do simple calculations using the following formula: $\rho = \frac{m}{V}$

The candidate is familiar with:

- the following phenomena:
  - the structure of our solar system: Sun, Moon and planets
- the following concept:
  - energy storage.

Subdomain C1 - Force and Motion

The candidate is able in particular contexts to analyse the relationship between force and changes in motion qualitatively and quantitatively and explain it using Newton’s laws.

Specification:
The candidate is able to:

1. do calculations of uniform linear motions
2. determine the properties of motions using position-time diagrams and speed-time diagrams

- recognize the following types of motion: uniform linear motion, uniformly accelerated/decelerated motion, free fall, motion of a falling object with friction
- calculate average speed from an (x,t) diagram
- calculate speed at a particular point in time from an (x,t) diagram, using the knowledge that speed is the derivative of position with respect to time
- calculate falling acceleration at a particular point in time from a (v,t) diagram, using the knowledge that acceleration is the derivative of speed with respect to time
- calculate distance and average speed from a (v,t) diagram using area

3. analyse the forces acting on a system using both a vector diagram and goniometric relationships, including assembling and resolving into components and determining the magnitude and/or direction of forces
   - forces: gravity, sliding friction force, rolling resistance force, air resistance force, normal force, tension force, muscle strength, resilience
4. explain and apply Newton's first law
   - concept: inertia
5. explain and apply Newton's second law
6. explain and apply Newton's third law
   - concepts: action force, reaction force, weight

The following formulas are included in these specifications:

$x(t) = vt$ as v constant $\qquad v(t) = at$ and $x(t) = \frac{1}{2}at^2$ as a constant

$$v_{aver} = \frac{\Delta x}{\Delta t} \qquad a_{aver} = \frac{\Delta v}{\Delta t} \qquad v = \frac{dx}{dt} \qquad a = \frac{dv}{dt} \qquad \rho = \frac{m}{V}$$

$$\vec{F}_g = -m\vec{g} \qquad F_{elastic} = Cu \qquad F_{w,\ell} = \frac{1}{2}\rho c_W A v^2 \qquad F_{w,s,max} = fF_N$$

$$\vec{F}_{res} = \Sigma\vec{F}_i = m\vec{a} \qquad \vec{F}_{AB} = -\vec{F}_{BA}$$

Subdomain C2 - Energy and Interaction

The candidate is able in particular contexts to use the concepts of conservation of energy, efficiency, work and heat to describe and analyse energy conversions.

Specification:

The candidate is able to:

1. do calculations relating to force, displacement, work, speed and power
   - determine work from a force-displacement diagram
2. analyse energy conversions
   - apply the law of the conservation of energy and the relationship between work and kinetic energy
   - at least the following types of motion: free fall, motion of a falling object with friction, vertical throw, vibration and bouncing motion
   - types of energy: kinetic energy, gravitational energy, spring energy, chemical energy, electrical energy, radiant energy, heat
   - concepts: potential energy, work (positive and negative), friction work, periodic motion
   - at least in the following contexts: energy consumption and energy saving in traffic, man in motion.

The following formulas are included in these specifications:

$$W = F\,s\cos\alpha$$

$$P = \frac{\Delta E}{t} = \frac{W}{t} = F\,v$$

$$E_k = \tfrac{1}{2} m v^2 \qquad E_g = m g h \qquad E_{elastic} = \tfrac{1}{2} C u^2 \qquad E_{ch} = r_v V \qquad E_{ch} = r_m m$$

$$\Sigma W = \Delta E_k \qquad \Sigma_{in} = \Sigma E_{out} \qquad \eta = \frac{E_{out}}{E_{in}} = \frac{P_{out}}{P_{in}}$$

Subdomain C3 - Gravity

The candidate is able at least in the context of the universe to analyse motions and explain them in terms of gravitational interaction.

Specification:

The candidate is able to:

1. analyse circular motions with constant orbital speed
    - do calculations of centripetal force only in situations where only one force has the role of a centripetal force. In constructions, drawings, and reasoning, it may happen that multiple forces fulfill the role of centripetal force.
    - concepts: orbital period, orbital radius, orbital speed
2. analyse motions of objects in a gravitational field using gravitational force and gravitational energy
    - analyse the motions of planets, comets and other celestial bodies using a numerical model
    - apply the relationship between escape velocity and the mass and radius of a celestial body
    - explain how falling speed at the planetary surface depends on the planet's mass and radius
    - concepts: gravitational interaction, elliptical orbit, geostationary orbit
    - at least in the following contexts: moon, planet, satellite.

The following formulas are included in these specifications:

$$F_g = G\frac{mM}{r^2} \qquad E_g = -G\frac{mM}{r} \qquad F_{cent} = \frac{mv^2}{r} \qquad v = \frac{2\pi r}{T}$$

Domain D - Charges and Fields

Assumed to be known:

The candidate is able to:

- draw and interpret circuit diagrams.

The candidate is familiar with:

- the following concepts:
  - conductor, insulator.

Subdomain D1 - Electrical Systems

The candidate is able in particular contexts to analyse electrical circuits using Kirchhoff's laws, and to analyse energy conversions. This is limited to the laws as they apply in series and parallel circuits. Candidates therefore do not need to know a more general formulation.

Specification:

The candidate is able to:

1. explain the phenomenon of electric current as displacement of charge due to an applied potential
    - use the definitions of current, potential/voltage and resistivity

- concepts: free electron, ion, elementary charge, voltage source, battery, accumulator/rechargeable battery

2. analyse circuits, calculating voltage, current, resistance and conductivity for series and parallel circuits
   - in the case of mixed circuits reason and do calculations
   - correctly connect an ammeter and a voltmeter
   - use the following components in a circuit: diode, LDR, NTC, PTC, ohmic resistor, light bulb, motor, heating element, fuse, earth-leakage circuit breaker
   - concepts: current division, voltage division, short circuit
3. analyse the power and efficiency of energy conversions in an electric circuit
   - do electrical energy calculations in joules and kilowatt hours
   - at least in the following contexts: light sources and domestic appliances (light bulb, energy-saving bulb, LED, electric motor, heating element and kWh meter), energy consumption, energy saving, generation of electricity.

The following formulas are included in these specifications:

note: symbol U is used for Voltage

$$G = \frac{1}{R} \qquad I = \frac{Q}{t} \qquad U = \frac{\Delta E}{Q} \qquad \rho = \frac{RA}{\ell} \qquad U = IR$$

for a series circuit: $U_{tot} = U_1 + U_2 + \dots \quad I_{tot} = I_1 = I_2 = \dots \quad R_{tot} = R_1 + R_2 + \dots$

for a parallel circuit: $U_{tot} = U_1 = U_2 = \dots \quad I_{tot} = I_1 + I_2 + \dots \quad \frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

$$P = UI \qquad E = Pt \qquad \eta = \frac{E_{out}}{E_{in}} = \frac{P_{out}}{P_{in}}$$

Subdomain D2 - Electrical and Magnetic Fields

The candidate is able in particular contexts to describe, analyse and explain electromagnetic phenomena using electrical and magnetic fields.

Specification:

The candidate is able to:

1. describe an electric field as the result of the presence of an electric charge
   - determine the direction of the electric field
   - concepts: repulsive and attractive electric force, homogeneous and radial electric field, field line
2. apply the relationship between voltage and kinetic energy to a charged particle in a homogeneous electric field
   - use electrical energy as a form of potential energy
   - explain the unit electron volt
   - at least in the following contexts: X-ray tube, linear accelerator
3. describe a magnetic field as the result of the presence of a moving electric charge
   - determine the direction of the magnetic field of a permanent magnet, a straight electric wire and a coil
   - concepts: homogeneous and inhomogeneous magnetic field, field line, electromagnet
   - at least in the following context: the Earth's magnetic field
4. describe the effect of a magnetic field on an electric current and on a moving charge
   - determine the magnitude and direction of the Lorentz force
   - at least in the following contexts: electric motor, loudspeaker
5. analyse electromagnetic induction phenomena in different situations
   - use the definition of flux

- apply the knowledge that the induced voltage is proportional to the number of windings and the change of flux per unit of time
- at least in the following situations: a moving magnet in a coil and a rotating wire loop in a homogeneous magnetic field
- at least in the following contexts: dynamo, microphone.

The following formulas are included in these specifications:

$$F_{el} = f\frac{qQ}{r^2} \qquad \vec{F}_{el} = -q\vec{E} \qquad \vec{E} = \frac{\Delta U}{\Delta x} \qquad \Delta E_k = -\Delta E_{el} \qquad \Delta E_{el} = qU$$

$$F_L = BI\ell \qquad F_L = Bqv \qquad \Phi = B_{\perp}A$$

$$U_{ind} \propto N \qquad U_{ind} \propto \frac{d\Phi}{dt}$$

Domain E - Radiation and Matter

Subdomain E1 - Properties of Substances and Materials
The candidate is able to describe the physical properties of gases, liquids and materials and to explain and analyse these properties using particle models.

concepts:
particle models, real and ideal gases, gas laws, Van der Waals forces, evaporation, vapour pressure, expansion of matter, heat capacity, specific heat, heat transfer.

Specification:
The candidate is able to:

1. use the molecular model of matter to explain phases and phase transitions
    - concepts: gas, liquid, solid, melting, solidification, evaporation, condensation, sublimation
2. explain heat transfer using material models
    - explain the relationship between heat flow and the thermal conductivity of a substance and do simple calculations of heat flow. (Heat flow means the amount of heat passing through a wall per unit of time, ignoring the effect of air layers on either side of the wall.)
    - concepts: conduction, flow, radiation
    - at least in the following context: energy-saving using insulation
3. describe temperature changes in a substance as the result of the application or removal of heat
    - describe temperature in terms of the motion of particles and explain that there is an absolute zero
    - describe specific heat as a property of matter
    - convert from degrees Celsius to Kelvin and vice versa
4. describe and explain the relationship between density and specific heat in metals
    - concept: atomic mass
5. describe and explain the relationship between heat conduction and electrical conduction in metals
    - concept: conduction electron
6. interpret stress-strain diagrams in terms of elastic and plastic deformation and do calculations of elastic deformations
    - concepts: tensile strength, stress, strain, Young modulus
7. explain macroscopic phenomena in substances in terms of the properties of molecules and their interaction
    - ideal and real gases
    - fluids, solids

- phase and phase transitions
- the kinetic interpretation of pressure, internal energy and temperature

8. describe how pressure is measured and how pressure differences can cause flow
    - manometer, barometer, blood pressure monitor
    - systolic pressure, diastolic pressure
9. apply the general gas law to an ideal gas:
    - absolute temperature scale
    - calculate pressure, volume or temperature
    - pressure and volume diagram
    - pressure and temperature diagram
10. describe volume changes in a substance as the result of the application or removal of heat
    - linear coefficient of thermal expansion, volumetric coefficient of thermal expansion

The following formulas are included in these specifications:

$$T_{Kelvin} = T_{Celcius} + 273 \qquad \rho = \frac{m}{V}$$

$$Q = m \cdot c \cdot \Delta T \qquad P = \frac{\Delta Q}{\Delta t} \qquad P = \lambda \cdot A \cdot \frac{\Delta T}{d}$$

$$\frac{\Delta \ell}{\ell_0} = \alpha \cdot \Delta T \qquad \frac{\Delta V}{V_0} = \gamma \cdot \Delta T$$

$$\varepsilon = \frac{\Delta \ell}{\ell_0} \qquad \sigma = \frac{F}{A} \qquad E = \frac{\sigma}{\varepsilon}$$

$$p = \frac{F}{A} \qquad \frac{p \cdot V}{T} = n \cdot R$$

The candidate is able to describe and analyse the properties of light in terms of geometrical optics and wave optics applications. The candidate is able to analyse the properties of light and apply them to techniques for recording images.

Concepts:
geometrical optics: refraction, reflection, refractive index, critical angle, dispersion
wave optics: frequency, wavelength, wave speed, interference, bending, grating, standing waves.

The candidate has a knowledge of:

- divergent, convergent and parallel light beams, shadow formation
- specular and diffuse reflection

Specification:
The candidate is able to:

11. do calculations using the laws of refraction
    - draw the optical path
    - angle of incidence, angle of refraction, refractive index
    - critical angle
12. describe the passage of light through a fibre optic cable and chromatic dispersion in a prism using the laws of refraction
13. describe what techniques and principles are used to record and transfer images and sound: digital technology; magnetic tape and compact disc
14. give examples of applications of ultrasound and laser light in healthcare:
    - ultrasound scanning
    - fibre optic technology.

Contexts:
camera, telescope, projector (video projector), microscope, fibre optic cable, human eye techniques for transferring or recording images and sound, laser.
The following formulas are included in these specifications:

$$i = t \quad \frac{\sin i}{\sin r} = n \qquad \sin g = \frac{1}{n} \text{ (with g : critical angle)} \qquad f = \frac{c}{\lambda}$$

Subdomain E2 - Electromagnetic Radiation and Matter
The candidate is able in astrophysics and other contexts to describe and explain the interaction between radiation and matter using the concepts of atomic spectrum, absorption, emission and radiation energy.

Specification:
The candidate is able to:
1. for bound electons,
   - determine wavelengths and frequencies of spectral lines from energy level diagrams;
   - explain absorption and emission spectra;
   - concepts: photon, ground state, excited state, ionization energy;
   - at least in context: atoms;
2. analyse the light from stars
   - use a Hertzsprung-Russell diagram to classify stars by temperature, total radiation output and size;
   - analyse the radial velocity of stars using the spectrum;
   - deduce the presence of elements in stars from the spectrum;
   - concepts: Fraunhofer line, red shift and blue shift.
3. Identify and apply the fact that hydrogen fusion is the main source of energy for stars.
   - Technical term: mass defect
4. describe and apply the relationship between emitted wavelengths and temperature
   - apply Wien's law
   - concepts: Planck curve, continuous spectrum
   - at least in the following contexts: light bulbs, stars
5. explain how the intensity of a star observed on Earth is related to the star's total radiation output and our distance from the star,
   - apply the Stefan-Boltzmann law;
   - at least in the following context: the Sun.
6. using appropriate tables and other sources, describe the different components of the electromagnetic spectrum and the properties of these types of radiation:
   - gamma radiation, X-rays, ultraviolet, (visible) light, infrared, radio waves, microwaves;
   - instruments: optical telescope, radio telescope, space telescope

The following formulas are included in these specifications:

$$E_f = hf \qquad \lambda_{max} T = k_W \qquad E_f = \frac{hc}{\lambda} \qquad E_f = |E_m - E_n| \qquad v = \frac{\Delta\lambda}{\lambda} c$$

$$E = mc^2 \qquad I = \frac{P_{source}}{4\pi r^2} \qquad P_{source} = \sigma A T^4$$

Domain F - The Quantum World and Relativity

Subdomain F1 - The Quantum World
The candidate can apply wave-particle duality and Heisenberg's uncertainty principle in contexts, and explain the quantization of energy levels in a few examples using a simple quantum physics model. One of the aspects of Heisenberg's uncertainty principle is the inability to talk about wave behavior and particle behavior at the same time; only this aspect is included in the syllabus. Candidates therefore do not need to know the general formulation.

Specification:
The candidate is able to:

1. explain the extent to which light exhibits wave and particle behavior,
   - explain the origin of diffraction at a single slit;
   - explain how and under what conditions maxima and minima arise at a double slit;
   - calculate the maxima in a grating
   - interpret interference patterns as probability distributions for the detection of photons; describe the structure of these patterns at low intensity and mention that photons interfere with themselves
   - reduce constructive and destructive interference to phase differences and path length differences and vice versa;
   - apply indivisibility as a characteristic particle property, for a photon at least in the context of specification E2.1
   - apply the principle that information about the path taken may prevent interference,
     - at least in the context of the double-slit experiment with which-slit detection;
2. explain the extent to which electrons exhibit wave and particle behavior, analogous to specification 1,
   - perform calculations using the de Broglie wavelength;
   - at least in the context of diffraction at crystal lattices;
3. Describe three quantum phenomena in some models for confined particles,
   - qualitatively describe a particle in an infinitely deep one-dimensional energy well using nodese and anti-nodes in a wave function and calculate the possible energies of the particle. The candidate does not need to be able to deal with linear combinations of wave functions, nor is knowledge of the relationship with the Schrödinger equation assumed. The use of the concept of wave function remains limited to the specification of context 3;
   - apply that in a finite deep one-dimensional energy well, the wave function and the corresponding probability distribution decrease exponentially in the barrier;
   - apply the energy spectrum of the hydrogen atom and explain that the discrete nature of the spectrum is related to the formation of nodes and anti-nodes in the wave function for the electron;
   - interpret (the square of) the position-dependent amplitude of a wave function as a measure of the probability of finding the particle at that location;
   - technical terms: quantization, ground state, excited state, tunneling;
4. Apply the principle that a maximum of one electron can be in the same state.
   - Use the phenomenon of electron spin as a magnet that can align with or oppose an external magnetic field, for example, two electrons with opposite spin.
   - state that in solids, the discrete atomic states combine to form nearly continuous energy bands with possible band gaps between them;
   - technical term: Pauli exclusion principle;
5. analyze materials and electrical components using the band gap concept:
   - in a solar cell
   - distinguish between conductors, semiconductors and insulators;
     - describe the operation of an LDR and an NTC;

The following formulas are included in these specifications:

$$\lambda = \frac{h}{m\,v} \qquad d\sin(\alpha_n) = n\,\lambda \qquad E = h\,f$$

$$E_n = \frac{13{,}6}{n^2} \qquad E_n = n^2 \frac{h^2}{8\,m\,L^2} \qquad (E_n \text{ in eV })$$

Domain H - Laws of Nature and Models

The candidate is able to recognize, list and apply fundamental physics principles and laws in examples within the subdomains of the Preliminary Examination. The candidate is also able to use a model and judge the limits of applicability and reliability of a particular model of a physical phenomenon.

Specification:
The candidate is able to:

1. recognize, list and apply fundamental physics principles and laws in examples relevant to the specifications of the domains in this syllabus, showing that the candidate has an overview of the entire course material and is able to combine topics from the various domains:
    - principles: universality, scale independence, thinking in terms of orders of magnitude, analogy
    - laws: laws of conservation, Newton's laws, quadratic law
    - concepts: law of nature, natural constant, relationship, equation
2. use examples relevant to the specifications of the domains in this syllabus to explain how the concept of modelling is used in physics and judge the limits of applicability and reliability of a particular model of a physical phenomenon
    - use the knowledge that a model is a simplified representation of reality and relate this to the limited applicability of the model
    - distinguish between a conceptual model, a scale model, a numerical model and a computer model

Domain I - Research and Design

Subdomain I1 - Experiments

The candidate is able in contexts within subdomains of the Preliminary Examination to do research by conducting experiments and analysing and interpreting the results.

Subdomain I2 - Model Studies

The candidate is able in contexts within subdomains of the Preliminary Examination to do research by conducting model studies and analysing and interpreting the results.

Subdomain I3 - Design

The candidate is able in contexts within subdomains of the Preliminary Examination to prepare, implement, test and evaluate a design based on a set problem.