Matura Exam in Physics

Oral Exam

Organisation

- You can choose your three most and three least favourite topics.
- The basics of mechanics (topics 1 to 3) and the basics of waves (14) are compulsory.
- Topics marked with an asterisk (*) are voluntary. They can be chosen as a most favourite topic.
- From each of the sections advanced mechanics (4 to 6), theory of heat (7 and 8), electricity and magnetism (9 to 11), oscillations and waves (13 to 16) and modern physics (17 to 19) only one topic may be taken as most favourite and one topic as least favourite topic. Section 14 (waves) is a compulsory supplement for both sections 15 (sound waves) and 16 (electromagnetic waves).
- All students of an examination group show up in front of the exam room 15 minutes before the exam starts.
- Every student is tested during 15 minutes on two different topics, one of which is one of the favourite topics. The least favourite topics are not tested.
- No aids such as a calculator or a formula book are allowed.

Information for the Preparation

Apart from physical contents the following skills are tested:

- Basic mathematical skills:
  - Algebraic transformations
  - Circumference and area of a circle, surface and volume of a sphere
  - Trigonometric functions (definition and numerical values for special angles), radian
  - Vectors: sum and difference (construction, calculation with components), scalar (dot) and vector (cross) product (geometrical meaning)
  - Approximations, limits
- Basic functions (algebraically and in graphical representation):
  - Proportionality and linearity, linear functions with two parameters
  - Simple power laws, especially squares (parabola) and inverse proportionality (hyperbola)
  - Trigonometric functions (amplitude, period, phase)
  - Exponential function (half life period)
  - Physical examples for functional relations
- Graphical representations (also see above):
  - Read/plot values from/in diagrams.
  - Determine slope and axis intercept of straight line fit.
  - Determine average of a function graphically (e.g. power vs. time diagram)
  - Add/subtract/multiply/square graphs
- Express physical phenomena in English
  - Describe formal relations between two quantities in words
  - Describe the behaviour of curves
  - Careful use of physical terms
- Careful, concise sketches which help to find a solution
- Ratios (How does x change when y changes by a factor k or by p %?)
- Consistent use of symbols, different symbols for different quantities (e.g. with indices)
- Powers of ten
- Units and unit prefixes, transformation between different units, reasonable precision
- Know orders of magnitude, e.g. speed of light, size of an atom, radius of the Earth, density of air, …
- Error estimates and error calculation

Subjects Overview

Remarks

- Physics does not only consist of formulae, but of the underlying concepts. There is no point in learning every formula in this brochure by heart without understanding what it means.
- The formulae in this brochure provide the basic tools to solve physical problems. The list is not exhaustive. You should always be able to derive other formulae from the basic ones.
- At the beginning of every section, some important terms are listed of which you are supposed to know the meaning and the definition. There are also some skills which are not related to calculations.
- You should know the constants at the beginning of every section with a reasonable precision.
- The symbols are generally the same as in "Formeln und Tafeln" and "Cutnell & Johnson" respectively.
- Always be aware of the scope of a law and of its possible applications.

1. Kinematics

Basic Terms:	Uniform motion:	*Time, position and displacement, velocity and speed*	
	Constant acceleration:	*Average and instantaneous speed, acceleration, free fall*	
	Superposition:	*Principle of linear superposition, projectile motion*	
	Circular motion:	*Period and frequency, angular velocity, centripetal acceleration*	
Skills:	Draw, interpret and transform displacement/speed/acceleration vs time diagrams		
Constants:	Acceleration due to gravity on earth and moon		
Definitions:	Speed	$v = \frac{\Delta s}{\Delta t}$	
	Acceleration	$a = \frac{\Delta v}{\Delta t}$	
	Frequency	$f = \frac{n}{\Delta t}$	
	Period	$T = \frac{1}{f}$	
	Angular Frequency	$\omega = \frac{2\pi}{T} = 2\pi f$	*Angle in radian*
Formulae:	Angular speed	$v = \omega r$	
	Centripetal acceleration	$a_R = \omega^2 r = \frac{v^2}{r}$	

2. Dynamics

Basic Terms:	Inertia and mass:	*Mass, density, inertial reference frame*	
	(Conservation of) momentum:	*Momentum, closed system, conservation of momentum*	
	Newton's laws of motion:	*Newton's laws of motion, force*	
	Dynamics of circular motion:	*Centripetal force*	
Skills:	Draw forces acting on an object, find components (graphically and numerically)		
	Set up and solve equations of motion		
Constants:	Densities of air and water		
Definitions:	Density	$\rho = \dfrac{m}{V}$	
	Momentum	$\vec{p} = m\vec{v}$	
Formulae:	Newton's second law	$\vec{F} = \dfrac{\Delta\vec{p}}{\Delta t} = m\vec{a}$	
	Force of gravitation	$\vec{F} = \dfrac{\Delta\vec{p}}{\Delta t} = m\vec{a}$	
	Elastic force	$F_F = D\,\Delta l$	
	Friction	$F_{R,G} = \mu_G\,F_N$	*Kinetic friction*
		$F_{R,H} \le \mu_H\,F_N$	*Static friction (inequality)*
	Air resistance	$F_L = \dfrac{1}{2} c_w \rho A\,v^2$	

3. Energy

Topics:	(Conservation of) Energy:	*Potential energy, kinetic energy, elastic energy, gravitational energy; conservation of energy*	
	Collisions:	*Elastic and inelastic collision*	
	Work and power:	*Work, power, efficiency*	
Skills:	Set up energy sums (also with non-mechanical energy forms)		
	Solve collision problems with conservation of energy and momentum		
Definitions:	Potential energy	$E_{\text{pot}} = mgh$	*Arbitrary reference level*
	Kinetic energy	$E_{\text{kin}} = \dfrac{1}{2}mv^2$	
	Elastic energy	$E_{\text{S}} = \dfrac{1}{2}D\,\Delta l^2$	
	Work	$W = F_s\,s$	*Alternative unit kWh*
	Power	$P = \dfrac{W}{\Delta t} = F_s\,v$	*F_s is the component of the force parallel to the direction of motion*
	Efficiency	$\eta = \dfrac{E_{\text{out}}}{E_{\text{in}}} = \dfrac{P_{\text{out}}}{P_{\text{in}}}$	

4. Gravitation*

Basic terms:	Kepler's laws:	*Planetary motion, swept area*
	Gravitation:	*Gravitational force, gravitational energy, escape velocity, Schwarzschild radius*
Skills:	Draw the orbit of a planet around the sun	
	Calculate the mass of a planet/star from a satellite's period of revolution	
	Calculate the escape speed from a star's mass and radius	
Constants:	Gravitational constant	
	Mass and radius of earth, moon and sun; distance earth - sun and earth - moon	
Formulae:	Kepler 1	The orbit of a planet about the Sun is an ellipse with the Sun's centre of mass at one focus
	Kepler 2	A line joining a planet and the Sun sweeps out equal areas in equal intervals of time
	Kepler 3	$(T_1 : T_2)^2 = (a_1 : a_2)^3$
	Gravitational force	$F_G = G \frac{m_1 m_2}{r^2}$
	Work in the gravitational field	$W_{A \to B} = G m_1 m_2 \left(\frac{1}{r_A} - \frac{1}{r_B} \right)$

5. Rigid Bodies*

Basic Terms:	Law of the lever:	*Torque, equilibrium (conditions)*
	Centre of gravity and equilibrium:	*Centre of gravity/mass; stable, unstable and indifferent equilibrium*
Skills:	Establish the equilibrium conditions for a rigid body	
	Determine the centre of mass from partial centres of mass	
Definitions:	Torque	$\vec{M} = \vec{r} \times \vec{F}$
Formulae:	Rotational equilibrium	$\sum_i \vec{M}_i = 0$

6. Hydrostatics

Basic Terms:	Pascal's principle:	*Pressure, hydraulic systems*
	Hydrostatic pressure in liquids:	*Hydrostatic paradox, communicating vessels*
	Air pressure:	*Air pressure, qualitative change in atmosphere*
	Buoyancy:	*Archimedes' principle, swimming objects*
Skills:	Explain how a mercury barometer works	
	Determine the immersion depth of a swimming object	
Definitions:	Pressure	$p = \frac{F_\perp}{A}$
Formulae:	Hydrostatic pressure	$\Delta p = \rho g h$
	Buoyant force (Archimedes)	The buoyant force on a submerged object equals the weight of the liquid displaced by the object

7. Gases

Basic terms:	Gas laws:	*Ideal gas, process vs. state; isothermal, isobaric, isochoric and adiabatic processes; amount of substance, molar mass*
	Kinetic gas theory:	*Particle model, distribution of molecular speed*
Skills:	Draw, interpret and transform diagrams for processes on an ideal gas	
Constants:	Molar masses of important elements (hydrogen, helium, oxygen, nitrogen, carbon)	
	Avogadro's number	
	Universal gas constant	
Definitions:	Molar mass	$M = \frac{m}{n}$
	Avogadro's law	$N = n\, N_A$
Formulae:	Ideal gas law	$pV = nRT$

8. Temperature and Heat

Basic Terms:	Temperature:	*thermal equilibrium; Celsius and Kelvin scale*	
	Internal energy:	*Work and heat for processes with gases*	
	Heat engines:	*Stirling process; heat engine, heat pump, refrigerator; efficiency of an ideal heat engine*	
	Specific heat:	*Specific heat; temperature of mixtures*	
	Heat transfer:	*Convection, heat conduction, radiation*	
	Phase transitions:	*Phase transitions; latent heat; vapour pressure diagrams, triple point, critical point*	
Skills:	Draw and interpret heat flow diagrams for heat engines		
	Describe the heat flows in mixing processes (with phase transitions)		
	Sketch the intensity vs wavelength diagram for heat radiation at different temperatures		
Constants:	Typical efficiency of a thermal power station		
	Specific heat of water		
	Solar constant		
	Latent heat of fusion and latent heat of evaporation for water		
Definitions:	Heat value	$H = \frac{Q^{\nearrow}}{m}$	
	Specific heat	$c = \frac{Q}{m\,\Delta T}$	
	Intensity of radiation	$J = \frac{P}{A}$	
	Latent heat	$L_{f,v} = \frac{Q_{f,v}}{m}$	
Formulae:	First law of thermodynamics	$\Delta U = Q^{\nearrow} + W^{\nearrow}$	
	Efficiency of an ideal heat engine	$\eta_C = 1 - \frac{T_k}{T_h}$	*Analogous expressions for heat pump and refrigerator*
	Heat conduction	$\frac{Q}{\Delta t} = -\lambda\, A\, \frac{\Delta T}{d}$ and $\frac{Q}{\Delta t} = -U\, A\, \Delta T$	
	Kirchhoff's law	$J = \varepsilon\, J_S$	
	Stefan-Boltzmann's law	$J_S = \sigma T^4$	
	Wien's law	$\lambda_{\max} T = b$	

9. Electrostatics

Basic terms:	Basic Phenomena:	*Elementary charge, conductors and insulators, charging by induction*
	Coulomb's law:	*Electrostatic force between point charges*
	Electric field:	*Field lines, dipole, homogeneous field, Faraday cage; magnitude of electric field*
	Electric potential energy, potential and voltage (potential difference):	*Work in the electric field, acceleration of charged particles*
Skills:	Draw field lines for a system of charges, calculate magnitude for a system of point charges	
	Calculate speed of charged particles from acceleration voltage (unit eV)	
Constants:	Elementary charge	
	Coulomb's constant	
Definitions:	Magnitude of the electric field	$\vec{E} = \frac{\vec{F}}{q}$
	Potential difference (voltage)	$\Delta V = \frac{W}{q}$
Formulae:	Force between two point charges	$F_C = \frac{1}{4\pi\varepsilon_0\kappa}\frac{Q_1 Q_2}{r^2}$
	Potential of a point charge	$V(r) = \frac{1}{4\pi\varepsilon_0\kappa}\frac{q}{r}$
	Voltage in a homogeneous field	$\Delta V = E\,d$

10. DC Circuits

Basic Terms:	Electric current and power:	*Simple circuits, power of the electric current*	
	Resistance:	*Characteristic of different loads; resistors; resistivity, temperature coefficient*	
	Resistor networks:	*Series and parallel circuits; internal resistance of a battery; measuring voltage and current*	
Skills:	Draw and interpret schematic circuit diagrams (with meters)		
Constants:	resistivity of copper		
Definitions:	Current	$I = \frac{\Delta Q}{\Delta t}$	
	Resistance	$R = \frac{\Delta V}{I}$	
Formulae:	Power of electric current	$P = \Delta V\, I$	
	Ohm's law	$\Delta V \propto I$	*only for (ohmic) resistors*
	Resistance of wires	$R = \rho\frac{l}{A}$	
	Temperature dependence	$\Delta\rho = \rho_{T_0}\alpha_{T_0}\Delta T$ or $\Delta R = R_{T_0}\alpha_{T_0}\Delta T$	*Formeln und Tafeln:* $T_0 = 20\ °C$
	Series wiring of resistors	$R_T = R_1 + R_2 + \ldots$	
	Parallel wiring of resistors	$R_T = \left(\frac{1}{R_1} + \frac{1}{R_2} + \ldots\right)^{-1}$	

11. Magnetism

Basic terms:	Ferromagnetism:	*Permanent magnet; earth's magnetic field*	
	Magnetic field:	*Magnetic field lines; force on a current-carrying wire, right-hand-rule*	
	Magnetic force (Lorentz force):	*Motion of charged particles in a magnetic field*	
	Electromagnetism:	*Magnetic field around a straight wire, at the centre of a current loop, in a coil/solenoid, in a Helmholtz coil*	
	Induction:	*Motional EMF; Lenz's law, eddy currents*	
Skills:	Draw magnetic field lines		
Constants:	Earth's magnetic field in Zurich (horizontal component and inclination)		
	Permeability of free space		
Formulae:	Force on a current	$\vec{F} = I\,\vec{l} \times \vec{B}$	*Direction: right-hand-rule*
	Magnetic force (Lorentz force)	$\vec{F}_L = q\,\vec{v} \times \vec{B}$	*Negative particles: left hand*
	Magnetic field of a straight wire	$B = \frac{\mu_0}{2\pi}\frac{I}{r}$	
	Magnetic field of a solenoid	$B = \mu_0 \frac{NI}{L}$	
	Induced emf in a wire	$\Delta V = vBL$	

13. Oscillations

Basic terms:	Simple harmonic motion:	*Kinematics, dynamics and energy of the simple harmonic motion*	
	Damping and resonance:	*Energy loss due to damping, envelope; driven oscillation and resonance*	
Skills:	Use the characteristic equation to determine an oscillation's period		
	Draw, interpret and transform diagrams for displacement, speed, acceleration and energy		
Definitions:	Characteristic equation	$\ddot{y}(t) = -\omega^2 y(t)$	
Formulae:	Simple harmonic motion	$y(t) = A\cos(\omega t)$	
	Maximum speed	$v_{\text{max}} = \omega A$	
	Maximum acceleration	$a_{\text{max}} = \omega^2 A$	
	Oscillation period	$T = \frac{2\pi}{\omega}$	
	Total energy	$E \propto A^2$	
	Period of a mass on a spring	$T = 2\pi\sqrt{\frac{m}{k}}$	
	Period of a mathematical pendulum	$T \approx 2\pi\sqrt{\frac{l}{g}}$	*Small angle approximation*
	Damped oscillation	$y(t) = A(t)\cos(\omega t)$	

14. Waves

Basic Terms:	Waves:	*Perturbation, wave carrier, coupling; longitudinal and transverse waves*	
	Linear waves:	*Representation for fixed time/fixed position; reflexion, superposition*	
	Harmonic waves:	Wavelength	
Skills:	Transform from fixed time to fixed position and vice versa		
Definitions:	Characteristic equation	$y(x,t) = f(x - vt)$	*linear wave*
	Harmonic wave	$y(x,t) = A\cos(\omega t - kx)$	
Formulae:	Wave number	$k = \frac{2\pi}{\lambda}$	
	Propagation speed	$v = \lambda f$	

15. Sound Waves

Basic terms:	Sound waves:	*Speed of sound in different media*	
	Sound pitch and intervals:	*Frequency ratio, scales*	
	Sound level:	*Sound intensity and level, decibel, phone scale*	
	Musical instruments:	*Standing waves; string and wind instruments; frequency spectrum*	
	Doppler effect:	*Moving source and/or observer, frequency shift for reflexion on moving object*	
Skills:	Sketch standing waves on strings and in pipes		
	"Add" intervals		
	"Add" sound intensity levels		
	Interpret polar diagrams for directivity of loudspeakers		
Constants:	Speed of sound in air		
	Basic intervals (octave, fifth, fourth, major and minor third, equally tempered half-tone)		
	Hearing threshold level and frequency range of the human ear		
Definitions:	Sound intensity	$I = \frac{P}{A}$	
	Sound intensity level (in decibel)	$\beta = 10 \log \frac{I}{I_0}$	*Rules of thumb*
Formulae:	Speed of sound in a gas	$v_S = \sqrt{\frac{\kappa R T}{M}}$	
	Speed of sound in a liquid	$v_S = \sqrt{\frac{1}{\chi \rho}}$	
	Transverse waves on a string	$v_S = \sqrt{\frac{\sigma}{\rho}} = \sqrt{\frac{F}{m^*}}$	
	Overtones of a vibrating string	$f_n = (n+1) f_0 = (n+1) \frac{v_s}{2l}$	*Nodes at both ends*
	Overtones of an open tube	$f_n = (n+1) f_0 = (n+1) \frac{v_s}{2l}$	*Antinodes of air motion at both ends*
	gedackt pipe (closed at one end)	$f_n = (2n+1) f_0 = (2n+1) \frac{v_s}{4l}$	
	Doppler effect	$f_R = f_E \frac{v_S \pm v_R}{v_S \mp v_E}$	*R: Receiver; E: Emitter sign defined by direction*

16. Electromagnetic Waves

Basic terms:	Types and propagation:	*Spectrum of electromagnetic wave ; speed of light in vacuum and in media; Intensity*
	Wave optics:	*Huygens' principle; interference, diffraction*
	Ray optics:	*Reflexion and refraction; lenses*
Skills:	Give an overview of the electromagnetic spectrum Draw the path of a light ray through a glass object	
Constants:	Speed of light in vacuum (air) Critical angle for total internal reflexion in glass	
Definitions:	Refractive index	$n = \frac{c_{\text{vacuum}}}{c_{\text{medium}}}$
Formulae:	Speed of light in vacuum	$c_{\text{vacuum}} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$
	Speed of light in a medium	$c_{\text{medium}} = \frac{c_{\text{vacuum}}}{n}$
	Electric and magnetic field vectors	$\vec{E} = \vec{B} \times \vec{c}$
	Intensity	$I = \frac{1}{2\mu_0} c B^2$
	Law of reflexion	$\vartheta_r = \vartheta_i$
	Law of refraction	$n_1 \sin \vartheta_1 = n_2 \sin \vartheta_2$
	Total internal reflexion (critical angle)	$\sin \vartheta_c = \frac{n_2}{n_1}$ *only for $n_1 > n_2$*
	Thin lens equation	$\frac{1}{d_f} = \frac{1}{d_o} + \frac{1}{d_i}$
	Lateral magnification	$\frac{D_i}{D_o} = -\frac{d_i}{d_o}$
	Condition for constructive interference	$\Delta r = m\lambda,\ m = 0, \pm 1, \pm 2, \ldots$
	Diffraction on a double slit/grating (maxima)	$\sin \vartheta_m = m \frac{\lambda}{d}$

17. Special Relativity*

Basic terms:	Postulates:	*Relativity postulate and speed of light postulate*	
	Relativistic kinematics:	*Simultaneity; time dilation, length contraction*	
	Relativistic dynamics:	*Relativistic energy and momentum; equivalence of energy and mass*	
Skills:	Calculate a relativistic particle's speed from the acceleration voltage		
	Calculate the energy set free in a nuclear process		
Definitions:	Speed (dimensionless)	$\beta = \frac{v}{c}$	
	Lorentz factor	$\gamma = \frac{1}{\sqrt{1-\beta^2}}$	*non-relativistic:* $\gamma - 1 \ll 1$
Formulae:	Time dilation	$t = \gamma\tau$	
	Length contraction	$l = \frac{\lambda}{\gamma}$	*Only parallel to motion*
	Energy-momentum relation	$E^2 = (mc^2)^2 + (pc)^2$	
	Equivalence of energy and mass	$E_0 = mc^2$	*Rest energy*
	relativistic energy	$E = E_0 + E_{\text{kin}} + \ldots = \gamma E_0$	
	Mass defect	$\Delta m = m_X - Zm_p - (N-Z)m_n$	

18. Quantum Physics*

Basic Terms:	Photoelectric effect:	*Work function, photon*
	Wave-particle duality:	*de Broglie relation*
	Atomic physics:	*Energy levels; resonance absorption*
Constants:	Planck's constant	
Formulae:	Energy of a photon	$E = hf = \hbar\omega$
	Photoelectric equation	$W_{\max} = hf - W_a$
	Threshold frequency	$f_{\min} = \frac{W_a}{h}$
	de Broglie wavelength	$\lambda_B = \frac{h}{p}$

19. Nuclear Physics*

Basic terms:	Radioactive decay:	*α, β and γ decay, daughter nuclei; decay law, half life period*
Skills:	Find daughter nucleus for α and β decay	
	Determine half life period from decay diagram	
Formulae:	Decay law	$N(t) = N_0\, e^{-\lambda t} = N_0\, 2^{-t/T_{1/2}}$
	Half life period	$T_{1/2} = \frac{\ln 2}{\lambda}$