Physics

Overview

An extended essay in physics provides students with an opportunity to apply a range of skills while researching a topic of personal interest in the field of physics. A physics extended essay is characterized by a particular emphasis on physics within a more general set of scientific criteria. An extended essay in physics must take the form of a research paper involving a hypothesis or a model, or a critical analysis, that demonstrates argumentation, comparison, or the extraction of relevant information or data.

The outcome of the research should be a coherent and structured piece of writing that effectively addresses a particular issue or research question and arrives at a particular, and preferably personal, conclusion.

Choice of topic

It is important that the extended essay has a clear emphasis on physics and is not more closely related to another subject. A physics extended essay should, therefore, have a basis in physical theory and emphasize the essential nature of the subject. An extended essay in an interdisciplinary area such as materials science will, if registered as a physics extended essay, be judged on its physics content, not its chemical content.

The purpose of the essay is not principally to inform the reader about a specific topic, nor should it be a summary of the latest discoveries in physics. The student must be personally involved with the subject matter and not simply an informant. The topic should represent a challenge for the student.

Some topics may be unsuitable for investigation because of safety issues. For example, experiments involving dangerous or carcinogenic substances, radioactive materials, lasers, microwaves, UV light, noise or heavy equipment should be avoided unless adequate safety apparatus and qualified supervision are available. Typical experiments done in class, not suitable in themselves as a basis for an extended essay, can be a source of good topics.

Students should choose a well-focused, well-defined and realistic topic that allows for an in-depth treatment. Broad or complex survey topics, for example, investigations into black holes, gravity, time machines, the Higgs particle or the fate of the universe, will not permit the student to discuss conflicting ideas and theories, nor to produce an in-depth personal analysis within the word limit. Also, by definition, some topics are not suitable for an extended essay in physics, which is an experimental science with a specific approach and techniques.

Students should also be careful to avoid research topics that go beyond the boundaries of conventional science, for example, areas that are more related to metaphysics or pseudo-science. Examples of this could include the unknown forces of pyramids, physics and God's existence, and extrasensory perception.

The following examples of titles for physics extended essays are intended as guidance only. The pairings illustrate that focused topics (indicated by the first title) should be encouraged rather than broad topics (indicated by the second title).

- "Orbital determination of a minor planet" **is better than** "Gravitation".
- "The variation in resistance of a wire subjected to different strains" **is better than** "Measuring the resistivity of different materials".

- "The use of interference fringes to measure small displacements" **is better than** "Making interference patterns".
- "The range variation of water flowing out of a hole in a container" **is better than** "An application of Bernoulli's principle".
- "The impact of the resistivity of the metal of a pipe and the pipe's wall thickness on the terminal velocity of a cylindrical magnet falling down the metallic pipe" **is better than** "Eddy currents".

Moreover, it may help if the student further defines the topic chosen for study in the form of a research question, followed by a statement of intent that indicates which broad process is going to be used in answering the question. In this way, the approach to the topic chosen may be even further clarified. Some examples of this could be as follows.

Title	**Black hole at the centre of the Milky Way**
Research question	Is it possible to determine the presence of a black hole at the centre of the Milky Way?
Approach	A data-based approach is taken. From the astronomical observations of a star following a Keplerian orbit around a compact radio source, the mass of a supermassive black hole is determined. The level of uncertainty is appreciated.
Title	**The wine bottle as a Helmholtz resonator**
Research question	Do wine bottles of different shapes behave as Helmholtz resonators?
Approach	An experimental approach is taken. The theoretical model is reviewed with specific emphasis on the physical and geometrical parameters determining the resonant frequency. By blowing across the opening of the bottle, a resonant frequency is produced, picked up and measured. The accuracy of the model is determined.
Title	**The deflection of starlight by the Sun's gravitational field**
Research question	What will be the angular deflection of starlight by the Sun if Newton's Universal Law of Gravitation is applied?
Approach	A theoretical (numerical) approach is taken. Assuming a corpuscular model of light, the motion of these corpuscles moving at the speed of light in a gravitational field is followed by iteration. The results are compared to the one derived from general relativity.
Title	**The efficiency of electromagnetic damping**
Research question	Is the efficiency of electromagnetic damping of a moving glider a function of the initial kinetic energy of the glider?
Approach	An experimental approach is taken. The energy budget of a coil-carrying glider going through magnetic braking on a linear air track is followed by comparing the mechanical energy lost to the thermal energy generated in the coil.

However, the aim of the essay may also be presented as a statement or as a hypothesis rather than an actual question. Some examples are as follows.

- The objective is to establish theoretically the proportionality existing between the terminal velocity of a cylindrical magnet falling down a metallic pipe and the resistivity of the metal of the pipe as well as the pipe's wall thickness. An experimental investigation follows.
- Water waves are observed in a long and narrow trough and their speeds are measured. It is assumed that, for shallow water, the speed of the wave will be proportional to the square root of the depth of the water and independent of the wavelength.
- The objective is to establish the relationship between power and temperature for an incandescent lamp.
- A retractable ballpoint will be used to test the law of energy conservation.
- The objective is to establish an acoustic model of the concert flute.

In first-hand experimental essays, students should choose sensible and feasible experiments that do not require extensive lengths of time for the construction of apparatus. Highly sophisticated instruments are not required: in some cases, they can impose limitations and hinder the understanding of a phenomenon. Successful experiments will produce relatively rapidly the data necessary for a sound analysis.

Ideally, students should carry out the research for the essay solely under the direction of the school supervisor. Some of the best essays have been written by students investigating relatively simple phenomena using standard school apparatus, and this approach is to be encouraged. Regardless of where, or under what circumstances, the research is carried out, students must provide evidence in the essay of their personal contribution to the research approach and to the selection of the methods used. Essays based on research carried out by the student at a research institute or university, under the guidance of an external supervisor, must be accompanied by a covering letter outlining the nature of the supervision and the level of guidance provided.

The domains of aerodynamics and hydrodynamics are theoretically and experimentally very demanding; for example, the construction of wind tunnels can be problematic and time-consuming. A topic within these domains must be chosen and defined very carefully.

Physics applied to sports can be a source of excellent topics, although the acquisition of sufficient valid data can sometimes be problematic. The relevant biomechanics can be overwhelming.

Students must choose a research question that can be treated effectively within the word limit and is not of a trivial nature.

Treatment of the topic

Every extended essay in physics will involve some research into the background or theory of the topic selected. However, extended essays in physics may then vary. Students may choose any of the following approaches.

- **Experimental:** design and implementation of an experiment, then personal collection and analysis of the data.
- **Data-based:** location and extraction of raw or processed data, not collected directly by the student, which is then further refined and analysed.
- **Theoretical:** development of a quantitative or semi-quantitative description of some physical phenomenon, exercise of the model, predictions about its behaviour and limitations.
- **Survey:** formulation of a cohesive, ordered, analytical and supported (qualitative and quantitative) discussion of the topic.
- **Combination:** some combination of the approaches listed above.

All extended essays in physics should summarize the scope and limitations of the work undertaken. This should always include analysis of any experimental design, uncertainties and

precision of data, mathematical techniques, relationships with theoretical models, and reliability and quality of sources. The essay content and development should directly evaluate the research question, possibly in the form of a test of a hypothesis.

Experimental essays allow students to display their own critical thinking skills in a more discernible fashion, but experimental work is **not** a requirement for a physics extended essay. However, a theoretical dimension must be part of any empirical investigation.

Any experimental work that forms part of a physics extended essay should be adequately described to allow the work to be repeated by others, who should achieve similar outcomes and conclusions. Particular care should be taken with data obtained through secondary sources. For data-based essays, the location and reliability of the sources needed should be considered at the start of the planning stage. Students must scrutinize such data and the experimental design with the same care that they would apply to data that they have collected themselves. A careful scrutiny of research procedures could reveal serious flaws in experimental design or in data collection that invalidate the results in whole or in part, or at least limit the interpretation.

A purely empirical investigation relating two or three variables in the absence of any theoretical foundation is **not** satisfactory—for example, an investigation involving only a mathematical analysis of the gathered data relating the index of refraction of an Epsom salt solution to the salt concentration. In such an essay, the student would be expected to investigate the theoretical physics relating the index of refraction to the concentration.

If a computer simulation of a theoretical model is used, the algorithms developed or employed should be thoroughly analysed and simulation outcomes compared with reality to check their validity. For essays involving a theoretical model (computer simulation) describing a physical phenomenon, the planning should include the initial postulates, the key steps in the running of the model and the simulation outcomes gathered. Charts or code fragments may be used in the body of the essay to illustrate how the model was translated into software, but the programs themselves should be placed in the appendix. Each line of code of a program fragment included in the body of the essay should count as two words towards the word limit. The focus of any extended essay that uses a computer to build and exercise models, or to analyse data, must be on the discipline of physics, not the software.

In theoretical, data-based or survey essays, an evaluation of the quality and reliability of the literature sources used must be part of the essay. Students must have read enough about the topic to make a value judgment about the reliability of the sources. This can be achieved by researching secondary sources or by performing their own calculations. Students should not hesitate to discuss conflicting ideas and present their own opinions with their own arguments. In survey or theoretical types of essays, proper planning should involve interrogating source material in light of the research question, so that the views of other scientists are used to support the student's own argument, and not as a substitute for that argument. It may thus be helpful for a student to challenge a statement by a scientist, in reference to the topic being studied, instead of simply agreeing with it, where there is evidence to support such a challenge.

Analysis must complement data or information and not simply repeat it, while an interpretation should be deduced logically from the data or information. Unfounded, far-fetched extrapolation should be avoided and shortcomings recognized. The discussion should not be a rewording of results; it should generate a solid interpretation of the results to be compared to published research on the topic.

Absolute reliance on textbooks and the Internet is discouraged and no extended essay in physics should be based exclusively on such sources. Textbooks should be consulted only insofar as they may stimulate original ideas, provide models of disciplined, structured and informed approaches, and encourage direct and personal involvement with the essay topic. If students make use of Internet-based sources, they should do so critically and circumspectly in full awareness of their potential unreliability. There are ways to verify the credibility of sources and a librarian could advise about this.

Introduction to the essay

In the introduction, it is usually appropriate to identify the relevant principles of physics. For example, the understanding of the motion of a cylindrical magnet falling inside a copper pipe requires the application and integration of the Laws of Electromagnetic Induction and Newton's Laws of Motion. Students are expected to show that they are able to identify completely the relevant theory in the context of the research question and can apply it correctly. In the previous example, a brief qualitative description of the forces acting on the falling magnet and their possible variations along its path will achieve this goal. If a historical set-up is appropriate, it should be restricted and focused rather than general and exhaustive. Some topics require some background foreign to physics—for example, physics applied to sports or archeology. In such cases, only the essential non-physics information should be provided in the introduction. If it is considered necessary that more information should be included, then the appropriate place for it is the appendix.

In the introduction, the student must also show why the topic is worthy of investigation. The opportunity or potential for creativity and initiative is a measure of the significance (importance) and worthiness of the topic chosen. Some topics may be unsuitable because the outcome is already well known and documented in standard textbooks, and the student may not be able to show any personal input.

Presentation

It is difficult to be precise about the 4,000-word limit in physics as most essays include tables, graphs, figures, diagrams, equations and calculations. Examiners will follow the spirit of the word limit so that an essay that is excessive in length will be penalized. For experimental or data-based essays, a typical layout will follow the order of tables of data, graphs, analysis and conclusion. If the investigation is divided into two or more parts, it is recommended to repeat this order for each part with a brief overview conclusion presented at the end of the essay. If data and graphs are too numerous, they should be included in an appendix. However, it is essential that the reader is able to follow the development of the essay without having to refer to the appendix. The core of the essay should be complete and stand on its own, with the collection of all tables, graphs and diagrams inserted in the order required to allow for an easy reading and understanding.

Tables, graphs and diagrams should be numbered so specific references can be made to them in the body of the essay. It is not necessary to include an appendix, but where one is used, it should not be done as an attempt to evade the 4,000-word limit. It is good practice to show one example of the calculations of numerical results, including the calculation of errors. The components of the table of contents should be made specific to the topic of the essay. A generic list of contents such as "theory", "experiment", "data", "analysis", "conclusion" and "bibliography" is not satisfactory. References should appear as footnotes in the body of the essay, independently of the bibliography. However, general knowledge such as Newton's Law of Gravitation, definitions, or the Doppler effect does not require any reference.

An extended essay in physics could include elements typically part of the report of an experimental investigation within the internal assessment documentation. However, the formal presentation of the extended essay is different from a laboratory report. For example, an annotated diagram can be included in the essay but an exhaustive list of equipment should not. Students are encouraged to look up scientific papers or articles published in recognized physics journals or magazines.

Academic level

Essays in theoretical physics should cover material extended from the Diploma Programme physics course covered in the classroom—for example, "The application of Huygens' principle to a single slit using the iterative method", or material from outside the course—for example, "The impact of solar light pressure on an orbiting satellite".

Essays in experimental physics should cover topics not included in the school course's regular investigations—for example, "Are the tiny droplets produced by the impact of raindrops on a hard surface electrically charged?".

Sophisticated computer interface equipment should be used as a tool, not an end in itself. The reliability and limitations of such equipment should be looked at. A simple use of simulation programs would not necessarily reveal a student's creativity and mastery of physics—for example, the simple measurements of the harmonics of a stringed musical instrument by an electronic probe would reveal little of the student's intellectual abilities.

Abstract

Students are encouraged to look at abstracts of scientific research papers published in recognized physics journals or magazines.

Interpreting the assessment criteria

Criterion A: research question

Although the aim of the essay can best be defined in the form of a question, it may also be presented as a statement or proposition for discussion. Whichever way it is formulated, the research question must be:

- appropriate to physics as a science; centred on physics and not on peripheral issues such as the history of physics or social implications of discoveries in physics
- identified clearly and set out prominently in the introduction.

An effective treatment within the word limit requires a narrow and well-focused topic.

Achievement level	Descriptor
0	The research question is not stated in the introduction **or** does not lend itself to a systematic investigation in an extended essay in the subject in which it is registered.
1	The research question is stated in the introduction but is not clearly expressed **or** is too broad in scope to be treated effectively within the word limit.
2	The research question is clearly stated in the introduction and sharply focused, making effective treatment possible within the word limit.

Criterion B: introduction

The introduction should relate the research question to existing subject knowledge: the student's personal experience or particular opinion is rarely relevant here. The relevant principles of physics should be situated in the context of the topic.

The introduction should not be seen as an opportunity for padding out an essay with a lengthy account of the context of the physics involved.

Achievement level	Descriptor
0	Little or no attempt is made to set the research question into context. There is little or no attempt to explain the significance of the topic.
1	Some attempt is made to set the research question into context. There is some attempt to explain the significance of the topic and why it is worthy of investigation.
2	The context of the research question is clearly demonstrated. The introduction clearly explains the significance of the topic and why it is worthy of investigation.

Criterion C: investigation

The way in which the investigation is planned will depend on the approach chosen by the student. However, the plan should include the relevant theory as well as an appreciation of the uncertainties or limitations inherent to techniques and apparatus.

Achievement level	Descriptor
0	There is little or no evidence that sources have been consulted or data gathered, and little or no evidence of planning in the investigation.
1	A range of inappropriate sources has been consulted, or inappropriate data has been gathered, and there is little evidence that the investigation has been planned.
2	A limited range of appropriate sources has been consulted, or data has been gathered, and some relevant material has been selected. There is evidence of some planning in the investigation.
3	A sufficient range of appropriate sources has been consulted, or data has been gathered, and relevant material has been selected. The investigation has been satisfactorily planned.
4	An imaginative range of appropriate sources has been consulted, or data has been gathered, and relevant material has been carefully selected. The investigation has been well planned.

Criterion D: knowledge and understanding of the topic studied

The knowledge and understanding demonstrated in a physics essay should extend from the Diploma Programme physics course or laboratory. The fundamental knowledge acquired in the classroom could be applied to a new physical situation that requires an interpretation of this knowledge. A purely empirical approach seriously limits the level of knowledge and understanding of the physics related to a topic, and consequently should be avoided.

Achievement level	Descriptor
0	The essay demonstrates no real knowledge or understanding of the topic studied.
1	The essay demonstrates some knowledge but little understanding of the topic studied. The essay shows little awareness of an academic context for the investigation.
2	The essay demonstrates an adequate knowledge and some understanding of the topic studied. The essay shows some awareness of an academic context for the investigation.
3	The essay demonstrates a good knowledge and understanding of the topic studied. Where appropriate, the essay successfully outlines an academic context for the investigation.
4	The essay demonstrates a very good knowledge and understanding of the topic studied. Where appropriate, the essay clearly and precisely locates the investigation in an academic context.

Criterion E: reasoned argument

Students should be aware of the need to give their essays the backbone of a developing argument. Personal views should not simply be stated but need to be supported by reasoned argument to persuade the reader of their validity. For example, it is not sufficient to write “From the graph we can see that…”. Straightforward descriptive or narrative accounts that lack analysis do not usually advance an argument and should be avoided.

A well-organized and well-presented essay will enhance the clarity of an argument.

Achievement level	Descriptor
0	There is no attempt to develop a reasoned argument in relation to the research question.
1	There is a limited or superficial attempt to present ideas in a logical and coherent manner, and to develop a reasoned argument in relation to the research question.
2	There is some attempt to present ideas in a logical and coherent manner, and to develop a reasoned argument in relation to the research question, but this is only partially successful.
3	Ideas are presented in a logical and coherent manner, and a reasoned argument is developed in relation to the research question, but with some weaknesses.
4	Ideas are presented clearly and in a logical and coherent manner. The essay succeeds in developing a reasoned and convincing argument in relation to the research question.

Criterion F: application of analytical and evaluative skills appropriate to the subject

Physicists use mathematics as a tool. This tool should not replace the relevant physics, nor become the goal itself rather than the instrument used to reach the goal. The student should show an understanding of the statistics and mathematical relationships produced automatically by software programs. A complete and solid understanding of the intrinsic limitations of an investigation, and their implications for the conclusions reached, is essential. It should be shown in some way that a given proposed limitation, possibly procedural, does have the expected impact on the final results and conclusion, for example, in the case where experimental results are

compared to standard values. A proper manipulation of significant digits and uncertainties, including uncertainty in the mean and in graphs, is expected, as well as an understanding of propagation of errors.

Achievement level	Descriptor
0	The essay shows no application of appropriate analytical and evaluative skills.
1	The essay shows little application of appropriate analytical and evaluative skills.
2	The essay shows some application of appropriate analytical and evaluative skills, which may be only partially effective.
3	The essay shows sound application of appropriate analytical and evaluative skills.
4	The essay shows effective and sophisticated application of appropriate analytical and evaluative skills.

Criterion G: use of language appropriate to the subject

Scientific language must be used throughout the essay. Students should be encouraged to read articles from recognized scientific journals or magazines to learn about the proper style, organization and presentation of a scientific paper. The essential quality of the language relates to exactness and precision, and typical expressions, such as “function of” or “proportional to”, carry specific meanings. A curve on a graph cannot be qualified as “exponential” or “quadratic” without proper analysis. Any symbols used must be clearly and fully identified in the context of the situation; for example, writing “t for time” would not be sufficient but writing “t for time during which the magnetic force is applied” would be precise and helpful.

Achievement level	Descriptor
0	The language used is inaccurate and unclear. There is no effective use of terminology appropriate to the subject.
1	The language used sometimes communicates clearly but does not do so consistently. The use of terminology appropriate to the subject is only partly accurate.
2	The language used for the most part communicates clearly. The use of terminology appropriate to the subject is usually accurate.
3	The language used communicates clearly. The use of terminology appropriate to the subject is accurate, although there may be occasional lapses.
4	The language used communicates clearly and precisely. Terminology appropriate to the subject is used accurately, with skill and understanding.

Criterion H: conclusion

“Consistent” is the key word here: the conclusion should develop out of the argument and not introduce new or extraneous matter. It should not repeat the material of the introduction; rather, it should present a new synthesis in light of the discussion.

The conclusion should reveal the impact on the final results of the investigation of uncertainties in experimental data, the limitations of a model or of an experimental design, or the validity of sources.

Achievement level	Descriptor
0	Little or no attempt is made to provide a conclusion that is relevant to the research question.
1	A conclusion is attempted that is relevant to the research question but may not be entirely consistent with the evidence presented in the essay.
2	An effective conclusion is clearly stated; it is relevant to the research question and consistent with the evidence presented in the essay. It should include unresolved questions where appropriate to the subject concerned.

Criterion I: formal presentation

This criterion relates to the extent to which the essay conforms to academic standards about the way in which research papers should be presented. The presentation of essays that omit a bibliography or that do not give references for quotations is deemed unacceptable (level 0). Essays that omit one of the required elements—title page, table of contents, page numbers—are deemed no better than satisfactory (maximum level 2), while essays that omit two of them are deemed poor at best (maximum level 1).

Achievement level	Descriptor
0	The formal presentation is unacceptable, or the essay exceeds 4,000 words.
1	The formal presentation is poor.
2	The formal presentation is satisfactory.
3	The formal presentation is good.
4	The formal presentation is excellent.

Criterion J: abstract

The abstract is judged on the clarity with which it presents an overview of the research and the essay, not on the quality of the research question itself, nor on the quality of the argument or the conclusions.

Achievement level	Descriptor
0	The abstract exceeds 300 words **or** one or more of the required elements of an abstract (listed above) is missing.
1	The abstract contains the elements listed above but they are not all clearly stated.
2	The abstract clearly states all the elements listed above.

Criterion K: holistic judgment

Qualities that are rewarded under this criterion include the following.

- Intellectual initiative: Ways of demonstrating this in physics essays include the choice of topic and research question, and locating and using a wide range of sources, including some that may have been little used previously or generated for the study.
- Insight and depth of understanding: These are most likely to be demonstrated as a consequence of detailed research, reflection that is thorough and well informed, and reasoned argument that consistently and effectively addresses the research question.
- Originality and creativity: In physics, these include looking inquisitively at the surrounding world, innovation in experimental procedures and equipment to measure variable parameters, an inventive approach to physical analysis or to classical topics, as well as the construction of imaginative theoretical models.

Achievement level	Descriptor
0	The essay shows no evidence of such qualities.
1	The essay shows little evidence of such qualities.
2	The essay shows some evidence of such qualities.
3	The essay shows clear evidence of such qualities.
4	The essay shows considerable evidence of such qualities.