May 2015 extended essay reports

Physics

Overall grade boundaries

Grade:	E	D	C	B	A
Mark range:	0-7	8-15	16-22	23-28	29-36

The range and suitability of the work submitted

The highly diverse topics chosen by candidates represent many domains of physics: mechanics is popular (motion in gravitational field, collisions, dynamics, rotational motion on an incline, energy exchanges, mechanical properties of materials, tensile strength of rope, oscillations of all types, aero and hydro-dynamics), interference of sound waves, waves, music and sound, radio wave propagation, effect of air pressure on rolling friction and on elasticity of balls, effect of temperature on the physical properties of materials, emissivity of an incandescent lamp filament, astrophysics, behavior of light in aqueous salt concentrations, music and sound, physics of sports (tennis, squash, surfing waves, trampoline), photovoltaic cells, magnetism, electromagnetic induction, water mills and heat engines, are some examples.

The initiative, creativity, determination, dedication and perseverance of a large number of candidates must be recognized. Many facets of scientific investigation are given.

The range of marks varies from excellent to, very rarely, elementary. Most essays fall into the middle range with few exceptional and few poor essays. Typically essays are experimental in their approach with some examples of data-based essay, simulation and survey type of essay.

Good error analysis distinguishes excellent essays and demonstrates insight into the underlying physics concepts and without irrelevant or marginally relevant commentary. They include a specific, clear, highly focused and detailed investigation with a personal touch and originality. Very good essays have a crisp theoretical or conceptual summary coupled to a carefully designed research question and study.

In some weak essays the physics is incomplete. In some cases the physics applied by candidates is so far off reality that it weakens or invalidates the work (e.g. failing to recognize rotational energy, moment of inertia, cases of non-uniform acceleration). Perhaps not in the syllabus, these physical elements are certainly accessible and understandable to an IB candidate who does minimal background research.

Very weak papers are casual, careless, trivial, superficial and derivative, poorly related to physics, and not proof-read.

A significant number of essays are purely empirical in nature. The candidate focuses on data collecting about a given phenomenon and providing the parameters of best-fit without any relation to physics theory or research into the background. No physical analysis is done, nor is there understanding of the event shown in a conceptual or mathematical sense of a model.

Some papers are original e.g. design of a bamboo flute (finger hole positions, prediction and analysis of sound produced). The challenge of essays on music is to focus on the relevant physics and not on subjective or psychological aspects of music. The challenge in sport oriented essays is to gather relevant physical measurement and do physics, not statistics. The biomechanics of human motion is highly complex.

There is a tendency to essentially focus on equipment, software (FFT) and the collection of data or graphs rather than the analysis of the results including relevant physics (model).

Survey essays tend to offer a summary of latest discoveries or theories related to a topic, often too broad or too advanced and without a personal input. Being simply an informant is not in line with the purpose of the extended essay, the candidate must contribute a personal touch, an added value. The essay should offer critical thinking, counter arguments or other opinions.

Examples of unsuitable topics presented this session: general relativity, time travel, string theory, perpetual motion, relativity and quantum mechanics dilemma, social implications of physics, human perception of light intensity, deeply complex and broad view of airfoils (aerodynamic).

Candidate performance against each criterion

Criterion A: research question

Generally the research question (RQ) is clear and suitable. However a significant number of RQs are too broad, not sufficiently focused and, at times, simplistic. There is trend toward essays with little possibility of developing a relevant physics theory or model. Occasionally the RQ seems to change between the abstract, introduction and conclusion. Good research questions are very specific, accessible and well grounded.

Criterion B: introduction

Candidates still have difficulty expressing an objective significance or worthiness, many give personal significance. A key element of the introduction, physical principles related to the RQ, is too often entirely neglected, without an overview of the relevant ideas and concepts or focused on ancillary physics rather than the RQ itself. Rarely the event is described in terms of these principles. This aspect of the introduction is to be differentiated from a formal theoretical development or the establishment of a model.

Criterion C: investigation

The majority of candidates reach achievement level 3. A good number of essays are well or satisfactorily planned investigations. Some candidates consult a limited number of relevant sources or gather insufficient data hence mistake the extended essay as an IA investigation report. A number of candidates do an investigation without planning or control experiments. As a consequence initial problems are not detected early. Inevitable failures and equipment glitches are part of research. Preliminary experiments can avoid problems that, unfortunately, show up only at the write-up stage. It is good to do some analysis as the data is collected so that the candidate can make the necessary improvements in equipment, methods and range of data collection hence reaching a more informed outcome. Generally an appreciation of uncertainties and limitations are included but, in a significant number of cases, not the relevant theory. Many candidates give a clear and complete description of the equipment, set-up and method, but not always in sufficient details e.g. specifications on impedance of meters, computer probes or microphones, release mechanism in ballistics.

A small number of candidates perform their experimental work in a university or industrial laboratory. The use of "black boxes" that automatically generate data tables and graphs with statistical analysis can make it difficult for the supervisor and reader to judge the level of knowledge and understanding, originality and creativity of the candidate.Criterion D: knowledge and understanding of the topic studied

Results are diverse. On one hand, a good number of essays include relevant and adequate quantitative physics (which plays a key role in the analysis) as well as a good understanding of it. On the other hand, increasingly, a significant number of essays do not include physics theory or very little of it, with a clear tendency to uniquely use a hypothesis. A purely empirical investigation seriously limits the level of knowledge and understanding of relevant physics. Some essays carry some relevant but incomplete physics, mediocre understanding or general underlying theory without focusing on the RQ. At times, standard bookwork is used as "filler" with no obvious connection to the essentials of the research. It can become an un-critiqued reading summary. A degree of knowledge is evident in most essays, but there is not always evidence of understanding; the building of a personalized theory is relatively rare. However some candidates achieve excellent research, challenging themselves successfully with quite advanced investigation beyond the IB syllabus. A hypothesis, often gratuitous without scientific explanation, does not replace a relevant physics theory or model from which predictions are made.

Criterion E: reasoned argument

A relatively small number of essays develop a reasoned and convincing argument throughout, well in line with the RQ. In other weaker essays, the tendency is to use the expression “it is evident that …" without any proof or any extracted data supporting the evidence, or insufficient support through failure to consult sources. In other cases, a lack of physics theory limits and weakens the argument. A limited amount of data gathered does not help some candidates develop a reasoned and convincing argument. There are cases where candidates come to unjustified conclusions based on the theory involved and not on the evidence of the investigation presented. Generally, essays present ideas in a logical and coherent manner in relation to the RQ, but with some weaknesses or only partially successful. Some candidates hesitate taking a clear and firm stand.

Criterion F: application of analytical and evaluative skills

A number of excellent essays present an analysis that includes predictions from a physics theory or model, a good amount of data and relevant information from literature as well as uncertainties and their propagation worked through methodically. The evaluation takes care of the limitations of the methodology and their impact on the validity of the results. Less successful candidates neglect one or more of these elements, the first element, physics theory, often being a key factor. Many opportunities to display student analysis, critical thinking, and reflection are not seized by relating a statement or value to a simple calculation or comparison (e.g., “what if …”, or, “given …, under the limiting conditions of … an upper-bound estimate would be …”, a comparable situation (e.g., “this can be related to … where we find that …”), an alternative perspective (e.g., force dynamics versus energy exchange analyses). Such interjections would highlight the student’s thinking, and that is what the essay is about.

Several candidates used best-fit curves generated from software without critical thinking, ignoring obvious trends. There is a fairly common belief that the statistical R- value is more important that the predictions of a model of the phenomenon. For example, different fit equations are “tried”, and parameters are determined, and a judgement is made about the suitability of the relation based solely on R-value. That is, in the student’s view, a good empirical fit using a relation that has no physical basis or scientific explanation can trump a meaningful physical relation because the statistics are better.

Some stated categorically that a relationship is cubic or exponential without any justification. Software removes a lot of the mechanical burden of plotting, but there is often *insufficient* attention paid to data points and their uncertainties. For example, lines of best fit forced unnecessarily to go through the origin, outliers that do not fit the line of best fit being disregarded, etc. An element of real concern is that the software offers automatic fitting and parameter estimation for various functions (usually polynomials of degree n, or sometimes exponentials) and students blindly fit to a function with no justification that is model-based or even intuition-based. This is not science. A good number of students are aware of uncertainties and work hard in taking them into account. A little more knowledge and guidance will help them become more efficient and successful. Skills in using software are recognized, better orientation in their use in the frame work of physics will make these skills more productive.

Most candidates attempt an evaluation with some success.

Criterion G: use of language appropriate to the subject

A limited number of candidates achieve the highest score in this multi-facetted criterion. The level of language, hence communication, and use of physics vocabulary is often satisfactory or good. Other weaknesses include omission of definitions of symbols or lack of consistency in their use and missing or wrong units for gradient, constant values, lack of precision or completeness in explanations. Only SI units are accepted. Often standards are not used in numerical values written with their units and uncertainties. For example, spacing between numerical value and units missing, or between different units in composite expression (speed in m s^{-1} not ms^{-1} since ms stands for millisecond). Writing F = (6.54 ± 0.03) N or F = 6.54 N ± 0.03 N is correct, rather than F = 6.54 ± 0.03 N. The use of power of tens is expected rather than numerical terms listing a series of zeros.

It is difficult to appreciate the use of language relevant to physics when the essay includes no or little physics. Sometime, colloquial or personal language is used, should be avoided. Slang language is inadmissible in a formal scientific report.

Overall, rarely is an essay very difficult to read with coherence impeded because of the level of language used. While language barriers may exist (and should be overlooked to a degree), it is clarity and correctness of physical concepts is vital when assessing this criterion.

Criterion H: conclusion

A limited number of essays present a conclusion that is fully consistent with the evidence, relevant to the RQ and complete with the impact of uncertainties and limitations. Stronger conclusions succinctly synthesized the results and discussion to clearly address the RQ. Also, specific values (range of controlled variables, graphical fits with parameters, precision and accuracy) are included. Typically some conclusions are unclear because the candidate expresses a contradictory conclusion or incomplete because the impact on the results of experimental design and methodology (limitations, uncertainties) or, possibly, the validity of sources are not stated. At times the conclusion is incomplete due to the fact that some essential parts of the discovery are ignored (writing "RQ is answered" is not enough) or, when applicable, unresolved questions not mentioned. When the outcome of an experiment is unexpected, the conclusion can be more challenging. Weaker conclusions introduced new ideas or observations rather than focus of the achievements.

Criterion I: formal presentation

The presentation is generally satisfactory or good though a number of candidates achieved top quality presentation. Significant efforts were made in a good number of essays, very little in some cases.

The formal elements (title page, table of contents, page numbers) are generally satisfied though some candidates omitting one of these are seriously penalized. Clear tendency to abuse the use of appendix and, to a lesser extent, footnotes. Excellent essays do not necessarily carry an appendix. Appendices and footnotes are not part of the essay *per se*.

Illustrative material.

A good number of essays present photographs. These are very often unlabelled, not annotated, poorly composed (clutter of equipment and background objects), obscure and too small (insufficient detail), hence more confusing than helpful. A proper (suitable, detailed) annotated scientific diagram of a set-up, with enhanced part(s) when needed, is more efficient. A number of candidates use good scientific schematic diagrams to illustrate sharply focused theoretical concepts hence enhance the physics with much less words in the narrative and greater clarity. Explanation are made easier, more compact. A good number of candidates numbered and labelled data tables and graphs but not always completely and not always referred to in the text by number.

Organization

Many candidates present their essay like an IA report with cookbook recipe style instructions for the procedure including a large number of unnecessary steps. An annotated diagram, possibly with an accompanying photo, and a few words that allow a reader to reconstruct the method will suffice. Good essays include only special relevant elements in the equipment or the procedure. Additionally, some essays spend one or several pages describing initial set-ups, how they fail, and what adjustments is made to create the final set-up. While this is sometimes interesting, this is not needed in the essay which should be a proof-read polished "formal piece of scholarship".

The core of the essay should stand on its own without any need to refer to the appendix (or footnotes). This insures clear and continuous flow of ideas. In well-presented essays involving multiple and repetitive raw/transformed data tables, and graphs, candidates include a *sample* of these only in the core and locate others in the appendix. At times, a summary table in the core of the essay can be very useful. Rarely candidates combine multiple graphs on one set of axes which both compact data presentation and explicitly highlight differences in results and relations.

Criterion J: abstract

A majority of candidates include the three requirement elements. A number of candidates achieve top marks here; but overall, the average mark is 1/2. The second element how "investigation was undertaken" is often incomplete and unclear, for example information given about what will be done but not how it will be done. In some cases, generic information is given rather that information specific to the investigation. The conclusion, at times, is limited with little information on what was actually achieved, no values, no equations, no comparison with literature. In some cases one element is missing entirely.

Criterion K: holistic judgement

Intellectual curiosity, wise choice of topic and RQ, physics content showing insight and full understanding as well as enthusiasm, perseverance, determination, personal engagement and contribution of an added value and some creativity characterize excellent essays. In most cases enthusiasm is evident. Candidates display an average and above intellectual initiative and depth of understanding but, often, insight is the least evident. The design of a new apparatus or adaptation, or the choice of a topic demonstrate the creativity of a number of candidates, time-consuming experiments show the determination and perseverance of candidates. It is generally clear when a candidate is making a commendable effort.

Recommendations for the supervision of future candidates

Selection of topic and RQ is a critical and consequential decision, which is an important step toward an interesting, enjoyable and productive piece of research, with resulting success. There is need for the EE supervisor to be proactive in early stages of the EE, ensuring students are considering a realistic and promising investigation. It is essential to detect early that an investigation will never work hence allowing a change of direction. Guidance during preliminary work plays a key role. Experimental investigations require preliminaries when inevitable failure, equipment glitches or issues come to light. The topic and RQ should:

- Be accessible to the student, highly focused and reflect the suggestions appearing under the Physics specific of the EE guide. A topic initially complex, after some exploration of simplified views, often can become a meaningful experimental investigation

- Have a quantitative physics content or model well in line with the RQ, possibly inspired from literature. Predictions from the model will be an important part of the analysis

- Take into account the different approaches listed under Physics specific in the EE guide

- Be an extension of IB physics and, in depth, more demanding than an IA practical activity

- Avoid being too obvious, too similar to a routine assessed practical activity, broad or vague or unclear, purely empirical in nature, too ambitious, grandiose or highly specialized, requiring extensive construction of equipment and set up, requiring unavailable instrumentation, without a physics theory backbone, without a sensible answer possible, with answer already well known, using inadequate apparatus, time wise too demanding, without personal engagement and the opportunity of being creative, with a limited amount of data or a limited scope.

Possible sources for help aside from the EE supervisor and physics teachers

- Mathematics and English teachers

- Librarian (Access to reliable sources on the Web, referencing, citations, bibliography, information literacy)Articles from scientific magazines e.g. *Physics Education* and *The Physics Teacher*. Rapid and *efficient* way to learn how focused the author is, refers to table, diagrams or graphs, how these are organized and presented, as well as equations

- EE Guide (general section and Physics specific)

- EE physics subject reports, past and present.

Language and communication

- Presentation and use of Excel or other software programs. Graphical analysis requires well set graphs. Excel can be of great service if candidate learns how to use it fully and properly in line with relevant *physics* variables and data collected:

    - Axes identified using physics symbols or terms of variables used in the essay, with units. Avoid use of x and y symbols

    - Divisions in sufficient number on both axes, drawing of horizontal *and* vertical lines (often missing) that permit easy reading of data points

    - Equations automatically generated by Excel should respect significant digits, carry the physics symbols used in the physics essay and avoid any extra(s) not referred to in the analysis

    - Good and readable size graph with data points spread over the graph, not crowded in a small corner

    - Irrelevant additions (e.g. nonsensical negative values on axes) to be avoided

- Standards

  Writing numerical values with proper units and uncertainties, and with proper spacing between numerical value and units is part of scientific language. Wise and useful to be aware of the SI standards.

- Symbols and terms definitions must be provided in the essay body at the point they are introduced *not* in a glossary of symbols and terms next to the Table of contents.

- Listings of equations, diagrams, tables and graphs not necessary

- General guideline

  Candidates are trying to communicate their understanding of a phenomenon, not just a collection of measurements and calculations. The essay should be written with fellow students as a possible audience.

Formal presentation

- Good to use a uniform font and style throughout the essay

- Output graphs from software (e.g. FFT graphs): good to introduce the graphs, identify the axes and any other relevant elements appearing on the screen/picture, a readable picture of good size. Similarly for a diagram reproduced from a source. In such a case, the reference of the source must appear with the diagram or graph as well as in the bibliography.

Research done in a university or industrial laboratory

- Essays based on such research carried out by the candidate, 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. (see EE guide under Physics specific). It is expected that the candidate will acknowledge such an assistance.

Supervisor report

- More reports are now written with relevant comments in line with criterion K. Many refers to the viva voce interview. These reports are read carefully by examiners, taken into account and well appreciated. It is hoped that the increase in useful reports will continue.