Qualifying Exam Preparation

Introduction

The goal of the Physics and Astronomy PhD Qualifying Exam (QE) is to ensure that students graduating with a Ph.D. have a demonstrated understanding of a broad range of physics topics at the undergraduate level. It is one of the only breadth requirements that graduate students need to fulfill. The QE is also often used as a diagnostic, especially for students taking it for the first time. Finally, the hours spent in preparation for the QE develop improved understanding of a range of physics… these hours spent strengthening, deepening, and broadening your knowledge of physics concepts and ability to solve physics problems are extremely valuable! It is part of our mission to assist you in your quest for eternal life in a way that is spiritually strengthening, intellectually enlarging, character building, and leading to lifelong learning and service.

We have assembled some ideas, tips, and methods for you to use to strengthen your preparation. Note that different advisers and students will not all agree on the value of the various insights provided here. You are encouraged to talk to your advisor, experienced students, and others to get improved perspective. You should use your own inspiration and intuition to identify what is best for you. There is likely much that you have already mastered thanks to your background… you could choose to build on those strengths or to shore up weaknesses. To make this useful for a variety of students and backgrounds, we have included a wide range of advice.

Research-validated studies on learning show that the ideal approach to a major challenge like QE preparation is to have a "growth-mindset" where difficult problems are challenges that create real learning. If you are not familiar with the growth mindset or related science about learning, stop reading right now and go study about the science of learning. (Our faculty like "Make It Stick" which is available freely (if on campus or using the VPN) on JSTOR (https://www.jstor.org/stable/j.ctt6wprs3). Chapter 1 and pages 201-211 from Chapter 8 are a good start.)

Choose to make your QE Preparation an opportunity for growth. Recognize that you will be developing conceptual reasoning, problem solving strategies, and metacognitive skills that are transferable to future courses, scientific research, and life. This preparation is a great time for you to focus on improving yourself in addition to learning or relearning specific physics concepts and equations.

For example, an excellent resource that identifies a variety of basic Physics Problem Solving strategies is Chapter 1 of David Morin's excellent "Problems and Solutions in Introductory Mechanics" available for free here:
http://www.people.fas.harvard.edu/~djmorin/ProblemsChap1.pdf At this point in your physics career, you should be very good at nearly all of these strategies; if not, now is a great time to improve!

What and how should I study?

By the nature of such broad exams, the questions in a particular area will focus on one or two particular subtopics. Therefore, one challenge in studying is to make sure that you cover a variety of topics and their subtopics (as listed on the website). One concern is that you will get a question from a subtopic that you don't know well. Despite this concern, it is prudent to identify only 8 or 9 of the 14 areas to study. Since only ~60% is required for passing, even if you can't remember anything about a question or two in the top 8, you can still do well. Therefore, it is typically not efficient to add a 10th area to study just for the purpose of making sure that have enough questions that you know how to do. Students that pass typically do well in at least 4/8 submitted responses; it is unusual (and concerning) to pass by getting ~half credit on all 8 questions.

The best way to do these problems is to practice, practice, practice. Much of this practice should be close to exam-like conditions (e.g., closed book / closed notes); more on this below. Work on past free response problems and send the solutions in to an expert (typically your advisor) to get detailed critiques. In topics where you need more materials, it is appropriate to reach out to a recent instructor of the most related course and to ask for class materials like notes, homework, exams, etc. (Responses will vary.)

Metacognition

Metacognition – the process of thinking about your thinking – is what separates experts from novices. Preparing for the QE is a major opportunity for you to improve your physics metacognitive skills. From studies of growth-mindset and neuroplasticity, we know that effective metacognition is a skill that is learned and developed and practiced.

Metacognition is divided into three main areas – Planning, Monitoring, and Evaluating – which mostly correspond to thought before, during, and after the main problem solving. Metacognitive reasoning typically takes the form of *questions that get you to think* with the goal of understanding yourself better and to use this understanding to set yourself up for success and to identify areas of improvement.

Metacognition can be applied to both studying for the Qualifying Exam and taking the Qualifying Exam. For example, metacognitive reasoning about *studying* for the Qualifying Exam might include questions like:

- Should I create a study group with other graduate students? Should I set up a timeline with my advisor?
- How am I budgeting my time? Have I given myself a reasonable amount of quality time to meet my goals? Do I need long uninterrupted times? What does my ideal studying time look like (e.g., phone turned off? music? at the library? snacks)? What is the subgoal of each session?
- Do I have the materials (textbooks, notes, online materials) I might need to refer to? How will I prioritize if I have too much?
- Based on past experience, which topics do I understand best? Where will I need the most work? Do I actively engage and spend more time on the more challenging areas (a sign of a growth-mindset)?
- Am I physically, mentally, and spiritually prepared to work on this activity? Should I change the way I eat, drink, or exercise to improve my studying? Have I considered praying (see Alma 34:24) and seeking inspiration for how to study and prepare? Is it time for some self-care?
- Am I focused on correct conceptual reasoning? Do I have an intuitive sense of how this concept works and why it is true? Can I explain the “why” behind various equations and concepts? Am I an expert at knowing which mathematical formulas/equations are relevant and applying them correctly?

- How will I decide when to move on to a new topic? How will I know that I have learned what I needed to learn? When should I return to a previous topic to review that material (consistent with effectively learning in *Make It Stick*)?
- Based on how previous sessions of studying for the qualifying exam went, what can I do to improve this and future sessions?
- Is now a good time to get external feedback from another student? from my advisor?

Advice on Writing Physics Free-Response Solutions

While the multiple choice part of the QE is important, most of your studying should be focused on prepare for the ”worked problem” free response section because 1) it is worth 2/3 of the points and 2) preparation for this part of the exam naturally prepares you for multiple choice questions as well.

Here is some advice on writing physics free-response solutions focused on the BYU Physics and Astronomy PhD Qualifying Exam. Some metacognitive questions are included (in *italics*) that you can ask yourself while you are taking the exam. **Practice asking yourself these questions during your studying so that you develop the metacognitive reasoning necessary to do well on the exam.**

The most critical aspect of free-response problems is that you get **significant partial credit** for showing your reasoning, calculations, and final conclusions. Unlike multiple choice questions, where a simple math error can lead to 0 points and the wrong answer, free response questions allow you to truly show your understanding of physics and to be graded on that. It follows that you should show your understanding of physics by writing out your solutions. Show that you think like a physicist/astronomer.

One of the best things you can do to see what is expected in these solutions is to write-up your responses to practice problems and ask a professor (probably your advisor) to grade them and to provide feedback on both the physics and the writing style. Start the problem with no notes and go as far as you can, then switch pen/pencil colors and study both your physics notes and these tips and finish writing it out. Have the professor explain their grading rubric. Typically points are granted for: understanding the key physical concept, identifying and correctly using the relevant equations, and correctly completing the problem. Subparts may not be graded uniformly; harder subparts are usually worth more points.

You should aim for your solutions to include significant detail, both in explaining yourself, the calculations, and the conclusions. You are writing solutions, not answers. In general, I would err on writing too much rather than too little... it's hard to lose points by writing too much (unless it's clearly incorrect), but it's easy to gain points by writing something correct. The disadvantage of writing too much is that it may take up too much time, but typically time is not a constraint on the Qualifying Exam.

When you first look at the exam, it may seem quite long and complicated to solve in such a short amount of time. But usually you will only be really pressed for time if you take a long time to figure out how to do something. If you remember all the physics and solve things correctly early on, you should have plenty of time to write out nice detailed answers.

Am I using positive self-talk? Am I approaching the questions with optimism?

How will I self-monitor the time I am taking on the exam?

Since all areas are worth an equal amount, you should look over the whole exam first. Choose the problems that you know the most about and work on them first, regardless of which question number it is. The difficulty level is probably mostly determined by your familiarity with the topic. One hint is to read the entire problem before starting even the first part. Not only does this help provide context for the whole question, but there are often hints for how to do the first subsections that are implied by how the later subsections are written.

A common mistake is to not carry out a question to completion. Read and reread the question and your solution until you are sure that you have ANSWERED EXACTLY WHAT IS ASKED. You would be surprised how many points were lost by well-written solutions that did not answer the question. Read the question through more than once, paying attention (underlining) all the quantities that are to be derived.

Would it help me parse the question if I rewrote the problem or subpart in my own words?

Not even the best students figure everything out instantly, so much of the time on the exam is spent in trying to remember or rederive equations, running through dead-end calculations, etc.

What do I do when I get stuck? Should I imagine explaining the solution to someone or an expert explaining the solution to me? Should I go try another question and let my mind incubate on this problem?

Should I try a different strategy? Am I using the full range of problem solving strategies like drawing diagrams, using units/dimensions, and considering limiting cases?

I recommend solving the problem twice. First, you go through the problem and figure out how to get the answer, the same as if it were a multiple choice question. You might organize your work a little more neatly than normal, but this is not your final solution. You're just figuring out how to get the solution. Then, you carefully write the solution to the problem using the hints and tips below based on your scratch work. Unless you instantly have a clear understanding of exactly how to get the answer, it is usually better to work it out on scratch paper and then write a clear well-written solution. If you can think of more than one way of doing a problem, work out the most logical and common one on your scratch paper. If there is another faster way that you can check quickly, then do that.

Pencil is recommended for writing these solutions. It's much easier to make minor edits and corrections. Your answers should be neat, orderly, and legible. Clearly label which problem part and subpart you are answering. Make it easy for yourself and the grader to figure out where you are and what you are doing.

You should always begin and end your answers **with words**. Explain the logical flow of your solution. Consider your audience to be a grader who wants to know that you understand things correctly; this means writing things out as if you were explaining them to some with a similar or stronger physics background from you, but who has not thought about the question at all. Your solution should be believable because you identify how you get from one part of the solution to the next. Another student, unfamiliar with the problem, should be willing to bet $10 that you got the right answer.

What grade would I give myself on this question? Why? How would I improve my answer if I imagined the grader was skeptical of my explanation? Does my explanation clearly demonstrate conceptual reasoning and understanding? Which part of my solution is the weakest?

Every variable (and symbol) should either be given by the problem, extremely common, or clearly defined by you. Try to use standard notation. Furthermore, if there is any ambiguity, you should clearly identify the coordinate system and/or reference frame relevant to each variable. (Being clear on this can often assist you in solving the problem in the first place!)

You do not need to rewrite the question statements, but quoting a few words here and there tends to be useful, particularly in the conclusion. For example, if a question asks for the final temperature of the gas, your conclusion can be, "Therefore, the gas T_f is " and then show the final (equation and) answer.

Proper spelling and grammar are nice, but not essential. In particular, don't worry about complete sentences or where to put the period or passive vs. active voice. Often the connecting text between equations is just a few words.

You can receive significant partial credit for showing your intermediate work, even if the final answer is wrong, and you can lose points for incorrect steps, even if they lead to the correct conclusion. For the most essential points in the answer, you may want to underline. For example, if the key point is to use conservation of angular momentum, you could say, "By conservation of L" and underline it.

Please draw figures and diagrams if they help to clarify the situation. Though you won't often see these in official solutions (because they are hard to make), they can be really helpful in showing that you understand the problem and how to solve it. If you drew a figure while you were sketching your solution and it had any value, I would draw it in your official answer solution as well. Make sure to label things (axes, vectors, etc.) very clearly.

Have a good sense of how accurately a problem needs to be solved. For example, astronomers are often happy if we know some values to within a factor of 2 or even 10. When the question uses words like “roughly,” “approximately,” or “about”, know that you are not looking for a precise answer and act accordingly. This often means ignoring secondary or lesser physical phenomena, things that would seriously complicate the answer. If your solution requires serious mathematical work (like numerically solving a PDE or iteratively solving a transcendental equation) there is almost certainly an easier way or you have tried to do it too precisely.

When you do make approximations or simplifications, explain them and justify them. If you are making a simplifying assumption (even one suggested by the problem), state it. For example, "we will ignore the electrical field lines not directly between the capacitor plates" or "using that $h << l$", where "<<" is physics/math talk for "much less", i.e., h/l is a small number and $(h/l)^2$ is so small that it can be ignored. Use the approximately equal sign when you are making such a simplifying assumption.

Always keep track of what units are being used. If there is any ambiguity, show the units inside your calculations. Generally, you should try to keep equations in the form of variables for as long as possible before substituting the numerical values. That makes it easier for you and the grader to see and understand any intermediate manipulation of the equations that you may do.

It is important to check that your answer is reasonable. This is an important practice. Specifically writing this out at the end of your answer is good. For example, after deciding that a nuclear reactor based power plant produced 500 MW of power, you can say "This has units of power, as desired, and seems like a reasonable amount of electricity production for a large power plant." Just because you found the number or expression that was asked for doesn't mean you can't end your problem with a brief concluding thought or two.

Does I answer exactly what was asked? Does it have the right units? Does the number make sense?

If you realize that you've done a question wrong, but don't have the time or the ability to go back and fix it, write down what you have figured out. Maybe at the end you get an unphysical answer or the wrong units. Don't try to trick the grader by ignoring these problems or by making up some incorrect quick fix... that very rarely works. If you're running out of time, it is better is to acknowledge that something was done wrong, write about where you think the issue was, and move on to another question.

Should I plan to come back to this question to check for any mistakes?

Free-response questions are usually multi-part questions, often with later parts building on previous parts. This makes it a little tricky whenever a mistake is made in an earlier portion. One nice aspect is that you will only lose points for a math error once... if all your numbers are off by a factor of 2 due to an error in the first calculation, you won't lose points for each "wrong answer", but only for the first one. Another nice aspect is that later calculations may make it obvious that you made a mistake earlier on, prompting you to go back and fix it, resulting in a fully correct solution. If, however, you find yourself in a later part of the question and your result from earlier simply doesn't work, you are best off following the advice above: admit that something is wrong and then explain how you would solve this subpart if you had a correct answer. You can get points for later parts, even if the previous parts were completely incorrect. Similarly, even if you can’t write anything about subpart 1, skip to subpart 2 which you may be able to answer and get full credit for.

Conclusion

This document covered a variety of skills and meta-skills that will assist you in preparing for the Qualifying Exam (along with many other exams and aspects of life). While you were likely familiar with many of these, spend some time **right now** identifying 2-3 areas where you can improve. Use inspiration to set goals that will support you in these improvements. Email a friend, your study group, and/or your advisor about these goals in order to hold yourself accountable. Passing the Qualifying Exam is an important part of your BYU Graduate School experience, so choose to act with the respect it deserves. Come back to this document throughout your studying, evaluate how you have improved, and repeat the process of setting new goals for improvement. As your intellect and problem solving abilities grow, you will fulfill the lofty goals of the Qualifying Exam.