

Feedback to candidates from the examiner: 28th January 2016

Course code: PHYS30101

Course Name: Applications of Quantum Physics

Introduction

In general, most people convinced me that they did understand what they were doing and were able to display a good understanding of quantum mechanics applied to a variety of systems. However, many marks were lost with silly slips or careless errors — it makes me feel awful when this happens, having to award fewer marks when the understanding is clearly there! Almost everyone could have improved their score by being a little more careful with the answers.

Compulsory Q1 attracted the highest average mark; but there was no difference at all in the average scores on Q2-4, despite more people attempting Q4. I suspect they were drawn there by the opportunity to answer more open discursive questions, but they did not do any better on it for the reasons outlined below.

Common misunderstandings

Generally displayed a good understanding of basic quantum mechanics at the right level; a few misconceptions on individual questions below.

Exam technique

These are the same as last year; they seem to be stubborn issues...

Where there are a number of marks allocated for more qualitative answers, full marks are likely to require a commensurate number of substantive points to be made. One-sentence answers to questions with several marks are not going to score highly. Moreover, in some cases, large volumes of text that didn't make sufficient substantive remarks will also not attract high marks.

A small number of scripts were incredibly difficult to read; if you have bad handwriting it needs working on. If the examiner can't read the answer, it's difficult to mark it.

Specific questions

Q1 was composed of a series of short problems covering a wide range of material from across the syllabus. Whilst overall marks were very good, performance fell into three groups. The first, a small minority, demonstrated little understanding of quantum mechanics at all; perhaps these students didn't come to lectures? The other two groups did demonstrate a sound knowledge of the basics of the course; one gained high marks and the other lost marks, but through silly slips rather than any major deficiencies in understanding quantum mechanics.

Part (a) on estimating tunneling probability was mostly very well done; common silly errors include missing out factors of two in calculating the probability, forgetting the square root or using electron rather than proton mass in the calculation.

Answers to (b) on simple ideas of probability and expectation values in a spin-1/2 system were reasonable. Common errors included: transposing a row matrix, but forgetting the complex conjugate in the calculation of the expectation value, or simple mistakes in handling of matrices or column/row vectors e.g. treating a column vector as a fraction.

Part (c) was almost universally well done; odd squares or factors were occasionally missed out and some specified the quantum numbers correctly as positive numbers but neglected to say they were integers.

In (d), most people knew the formula for a first-order shift in energy and the appropriate unperturbed eigenfunctions, but few people spotted that the integral was easily seen to be zero from the odd/even nature of the integrand. Many slogged through the integral in detail reaching the correct answer (I smiled at the comment of "Seriously!" after a correct calculation) but some didn't get the right answer due to slips in the algebra.

Most people could determine the bosonic nature of the two-particle wave function from exchange symmetry, but some didn't read the question properly and told me why the wave function was entangled instead.

Q2 was a more involved question on angular momentum and perhaps naturally got lower marks than Q1, although there was sufficient there to convince me that most people understood what they were doing.

Some people explained what the individual commutators said i.e. this commutes with that, but didn't relate it to measurements. Some related the commutators given in terms of measurements, but failed to give a general statement that you could determine the length and any one component.

In deriving the operator for L_x , there was quite a lot of sign fudging! Often the minus sign in the definition of the linear momentum operator was forgotten and one added to the definition of L in terms of r and p to make sure the signs worked to prove the form of L_x . Some tried to deduce forms of the operator from the commutators, which is futile since the commutators are independent of coordinate system and you are being asked for a operator in Cartesian form.

I got bitterly disappointed by the number of people who failed to notice that you needed the product rule to differentiate ψ with respect to z .

On the last part, some could articulate that when you operated with the raising operator and got zero meant you'd gone over the top of the ladder so that the state you operated on had $m=\ell$, but then failed to finish it off by noticing this meant that $\ell=1$.

Q3 Attracted a similar average mark to Q2 and again overall the class seemed to have a reasonably good understanding of magnetic effects in atoms. However, the final part on an atom in a strong magnetic field was not done well.

In the first part, marks were lost for not giving sufficient detail about the physical origin of the spin-orbit effect. Just saying that it was the interaction between spin and orbital angular momentum was clearly not enough, but as with the comment

above, the marks allocated suggest several substantive comments or issues should be mentioned.

Deriving the separation of different states in a spin-orbit multiplet was done well. A few people missed that L and S were common between the two states and there was the odd slip in calculating $J(J+1)$ for J and J-1.

Almost everyone deduced the correct value for L from angular momentum coupling. Marks were lost when comparing the experimental and theoretical separations of the levels with different J in magnesium. In order to get full marks you need to clearly express what is expected, what is measured, explicitly compare the two and then make some comment on the comparison. Different people missed out different parts of this so only a few got full marks.

The discussion of the Paschen-Back effect in the last part was poorly done. The majority missed the clue in the question; as it was a *strong* field you need to consider magnetic effects first, so L and S don't couple to make J. Most diagrams still had levels that were labeled with J values as good quantum numbers. Such effects do arise in the *weak*-field Zeeman effect, but not in a strong field.

Q4 A popular questions, perhaps because the questions posed appeared less mathematical. However, in all cases, very careful and accurate textual descriptions were needed and illustrated by mathematics in order to gain full credit. In addition, more discursive questions can often solicit pages and pages of text that make very few substantive points. So despite being popular, presumably because it was felt to be easier, it got the same average mark as Q2-4.

The first part of the question on eigenvalues was on the whole answered very well. However, a significant minority of people did not read it accurately and only answered either the part showing α_y and β_y where eigenstates OR the part α_z and β_z expressed in terms of them, clearly losing marks by not completing the whole question. A common error was to miss that α_y and β_y were complex column vectors, so when subtracting to form β_z , which is real, there needed to be a factor of $-i$.

Descriptions of encoding quantum information were good on the whole, and marks were generally lost for not making enough substantive points.

In order to properly describe quantum entanglement, precise language about measurements is needed to avoid misunderstandings and logical inconsistencies, especially when the concept is extended to more than two particles. Here the full answer required a description of the general concept (where the measurements of one part of the system effect the probabilities of outcomes of the other part of the system) and then illustrate that with the wave function given. Things like «the state of one depends on the state of the other» where not sufficient for full marks.

The next part did say «explain how» rather than just «give the» results in the two different circumstances so some marks were lost by just a statement.

The last part of the question contained many traps that prevented the award of all the marks, and the only way not to fall into them is to use very precise language combined with a high standard of clarity in the answer. Here are some examples where answers introduced confusion or did not give a full answer:

- Not being clear about whether you referred to situations where spies used the same analyser or where they both used S_z .

- Where a specific set of measurements were used to make a point, but the other eventualities were ignored or not referred to.
- Exactly what subset of data does «50% of the time» refer to? The whole time? Or just when they use the same analysers?
- On a similar point, is N the total number of measurements made or the number made under certain circumstances?
- The spies in this case, when Evan is not there and they use the same analyser, measure opposite spin components. So comments about them measuring «the same information», «the correct results», «the wrong results» were ambiguous at best.
- Equations were often just written down with no words of explanation; to give a cogent answer they need explaining and punctuating to the discussion.
- Answers purely couched in terms of the orientation of analysers, without reference to measurements, where invariably inaccurate.
- Some answers introduced terms with three factors e.g. $\alpha(A)\beta(B)\alpha(E)$; clearly wrong as there are only ever two particles.
- In some of the mathematics, when discussing the use of different analysers, the z-eigenstates for both particles were converted into expressions for y-eigenstates, rather than just the particle that was going to be measured with S_y .

As a result of these inaccuracies, mistakes and confusion, very few people managed to get high marks on the last part. This also suffered most in terms of illegible handwriting. That said, most people could at least articulate that the presence of Evan disturbs the measurements of Amanda and Brenda and that they could notice the disturbance by sharing some of their data. So it was hard to get zero marks, but common to get low marks!