NTNU
Det skapende universitet

Institutt for fysikk

**Eksamensoppgave i**

**TFY4170 - Fysikk II**

**Faglig kontakt under eksamen: Justin Wells**

**Tlf.: 45 16 36 97**

**Eksamensdato: 08.08.2017**

**Eksamenstid (fra-til): 0900-1300**

**Hjelpemiddelkode/Tillatte hjelpemidler: *C***

**Annen informasjon**:

Eksamen teller 100% på sluttkarakteren.

Du kan svare på Engelsk, Bokmål eller Nynorsk.

**Målform/språk: English.**

**Antall sider med oppgaver: 2**

**Antall sider med formler og uttrykk: 2**

**Kontrollert av:**

Dato Sign

**Question 1: Interactions with barriers**

In this question, we will investigate how waves and particles behave at barriers.

Consider a particle (for example, an electron) with kinetic energy $E_k$, travelling towards a solid wall (i.e. an infinite barrier) at an arbitrary angle.

**a) Describe (in words) what happens to the electron when it reaches the wall.**

**b) Solve the Schrødinger equation for the particle before and after it hits the wall**

**c) Under what conditions is it possible for the particle to penetrate into the wall?**

**Question 2: The *Scanning Tunnelling Microscope* (STM)**

An STM is a type of microscope which is commonly used to measure the structure of surfaces. In the case of an STM, the gap between a conductive "tip" and a conductive sample creates a barrier through which electrons can only penetrate by quantum mechanical "tunnelling".

**a) What is meant by "tunnelling"?**

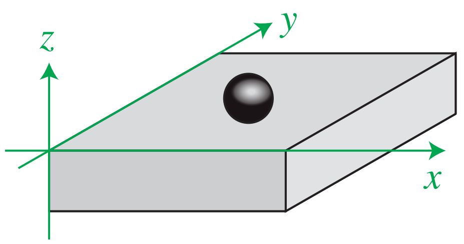
**b) Describe the conditions required in order for the STM to operate (i.e. tip potential, sample potential, tip-to-sample-distance, etc.)**

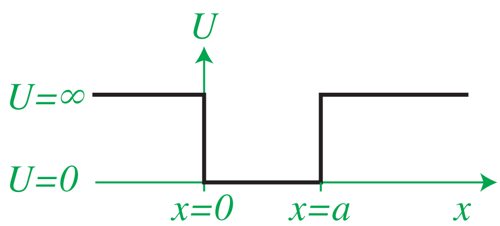
**c) If you use an STM to study a sample, what information do you think it would be possible to get about your sample?**

**Question 3: This question is about quantum dots.**

Consider that we have made a "quantum dot". This is a small sphere of metal on an insulator surface (see figure). Such a device would be easy to make in NanoLab.

We would like to be able to calculate the separation between the (quantised) energy levels. Since the "dot" is 3D, we should use the 3D Schrødinger equation. However, to start with, we will instead use a 1D approximation (as illustrated in the figure).




We will also assume that the potential inside to dot is $U$=0, and that it is infinite elsewhere.

**a) Do you think this is reasonable? How will it affect the estimate of the energy levels?**

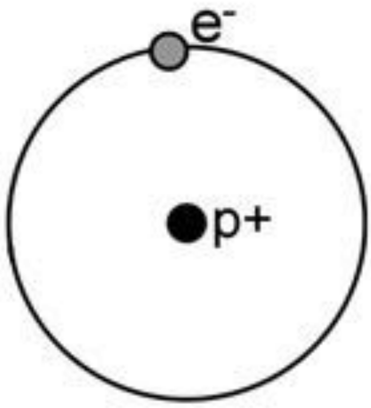
**b) Solve Schrødinger's equation for the 1D "dot" and find an expression for the energy levels.**

**c) Estimate how big should our "dot" should be in order to be electrically conductive at a temperature of 300 K, but not at 100 K.**

**d) Describe the assumptions you have used when carrying out the estimation in part c.**

**Question 4: Understanding atoms**

Consider an electron in orbit around a proton. This is known as the "planetary model" of an atom (in this case, the atom is hydrogen).




**a) Do you expect this orbit to be stable? i.e. describe any relevant energy-loss mechanisms, and the implications of energy loss from the electron-proton orbit**

Niels Bohr postulated that "special orbits exist" and that these special orbits have "orbital angular momentum $L$ as an integer multiple of $h/2\pi$".

**b) What is special about these orbits? What implication does $L = nh/2\pi$ have for the wave properties of an electron in an orbit?**

In the above expression for orbital angular momentum, "n" is a quantum number?

**c) What is the physical meaning of "n"?**

**d) In fact, we need to use more than one quantum number to describe an electron: what are the other quantum numbers, and what physical property are they describing?**

**Question 5: The photo-electric effect.**

In 1921, Einstein was awarded the Nobel Prize for correctly describing the photo-electric effect. The reason for awarding the Nobel Prize is that this experiment cannot be described using classical wave physics, and therefore, it was seen to be an important proof of the quantum mechanics.

**a) Briefly describe the photoelectric effect - it is strongly recommended to draw a figure.**

**b) Describe what you would expect to happen if you use only a knowledge of classical waves.**

**c) Describe what is really happening using a "quantum" perspective.**

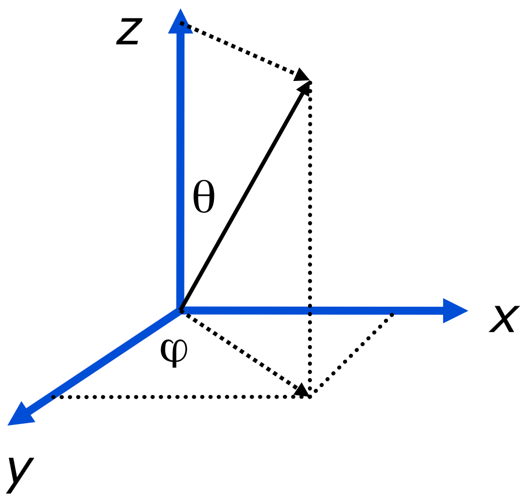
Additional information

Schrødinger equation in 1D:

$$\left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2}+U(x)\right]\Psi(x)=E\Psi(x)$$

Schrødinger equation in 3D (radial coordinates):

$$\frac{-\hbar^2}{2m_r}\nabla^2\psi(r,\theta,\varphi)+U(r)\psi(r,\theta,\varphi)=E\psi(r,\theta,\varphi)$$




Quantum mechanical probability:

$$\mathbb{P}=\int\psi(x)\psi^*(x).dx$$

The Coulomb force: $$F=k\frac{Q_1Q_2}{r^2}\qquad k=\frac{1}{4\pi\epsilon_0}$$