UNIVERSITY OF AGRICULTURE, ABEOKUTA

DEPARTMENT OF PHYSICS

PHS 352…Quantum Physics (3 units)

Module	**Short-Description**	**Duration**
1	Genesis of Quantum Physics	2 lectures
2	wave-particle duality	2 lectures
3	Basic principles of Quantum Physics	4 lectures
4	Commutator Relations in Quantum Physics	2 lectures
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		10 lectures

References:

1. Mathews, P.T.: Introduction to Quantum Mechanics
2. Pauling,L and Wilson,E.B. : Introduction to Quantum Mechanics
3. R. Shankar ; Principles of Quantum Mechanics
4. A. Ghatak and S.Lokanathan ;Quantum Mechanics

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Module 1(Genesis of Quantum Physics)
(2 lectures)

1.1 Genesis of Quantum Physics

Brief description of experiments and theories of Quantum Physics summarized as follows**:**

(a) Blackbody radiation.…Planck
(b) The photoelectric effect…Einstein
(c) Quantum theory of atomic states…Bohr
(d) The Davisson-Germer experiment…de Broglie hypothesis
(e) The uncertainty principle.…Heisenberg
(f) Probability waves..Born
(g) wave equation…Schrodinger
(h) Exclusion principle…Pauli

Module 2(Wave-Particle Duality)
(2 lectures)

2.1 Wave-particle duality of electromagnetic radiation

(a) Particle characteristics to explain:
   (i) photoelectric effect,
   (ii) Compton scattering
(b) Wave characteristics to explain:
   (i) Interference
   (ii) diffraction experiments.

2.2 Wave-particle duality of matter

De-Broglie hypothesis

Module 3(Basic principles of Quantum Physics)
(4 lectures)

3.1 Basic Principles of Quantum Physics

There are 4 basic princples of Quantum Physics summarized as follows**:**

(1) Observables and operators
(2) Measurement in Quantum Physics
(3) The state function and expectation values
(4) Time development of the state function

Tutorial 1

1. Consider the operators $\hat{D}, \hat{I}, \hat{B}, \hat{P}, \hat{\Theta}$ defined below as :

$$\hat{D}\psi(x) = \frac{\partial}{\partial x}, \hat{I}\psi(x) = \psi(x), \hat{B}\psi(x) = \frac{1}{3}\psi(x), \hat{P}\psi(x) = 3\psi^2 - 2\psi, \hat{\Theta}(x) = 0$$

For each of the operators listed above,construct the square,that is $\hat{D}^2$.

2. Let X be the one-dimensional position operator , $X\psi = x\psi$, and let D be the derivative operator: $D\psi = {d\psi}/{dx}$. Calculate DX

3. The state $\psi(x)$ of a system of electrons of mass m in 1-D is given by

$\psi(\mathrm{x}) = \mathrm{Ae}^{-2\pi x^2}$.

(a) Normalize to determine the value of A.
(b) What is the normalized state function?
(c) Calculate the average energy of the electrons in this normalized state.

4. The **Dirac delta** function $\delta(x-a)$ may be accurately expressed as an eigenfunction of $\hat{x}$ in the coordinate representation.

Evaluate the following: (i) $\int dx\delta(x-2)$ (ii) $\int dx(x-4)\delta(x+3)$

(iii) $\int dx(\log_{10} x)\delta(x-0.01)$ (iv) $\int dx(e^{x+2})\delta(x+2)$

(v) $\int_0^\infty dx[\cos(3x) + 2e^{ix}](\delta(x-\pi) + \delta(x))$

5. Consider a free particle moving in 1-D space such that the states are given by $\phi_1(x) = Ae^{-ikx}$ and $\phi_2(x) = B\cos kx$, where A,B and k are constants.

(a) What **momentum** is associated with the particle when in state $\phi_1(x)$?
(b) What **energy** is associated with the particle when in state $\phi_1(x)$?

(c) What **momentum** is associated with the particle when in state $\phi_2(x)$?

(d) What **energy** is associated with the particle when in state $\phi_2(x)$?

(e) How do the states $\phi_1(x)$ and $\phi_2(x)$ differ with regard to measurements of **momentum** and **energy**?

6. The time-dependent state $\psi(x,t)$ of a 1-D system is given by:

$$\psi(x,t) = e^{i\beta t}(A\sin \alpha x + Bi\cos \alpha x) \; .$$

If the potential energy is given by V_0 ,

(a) determine whether $\psi(x,t)$ is an energy eigenfunction. **(5 marks)**

(b) If so, calculate the measurable energy value in terms of α .**(10 marks)**

(c) What is the measurable energy value in terms of β ? **(10 marks)**

Module 4 …. Commutator Relations in Quantum Physics
(2 Lectures)

Definition : The commutator between 2 operators A and B is :

$[A, B]$ such that :

$$[A, B] = AB - BA \qquad (2.1)$$

4.2 Property : If $[A, B] = -[B, A]$ **,** the 2 operators A and B are said to commute with each other. i.e. A and B are ***compatible***.

Thus $AB = BA$ (2.2)

i.e. $[A, B] = 0$ (2.3)

If $[A, B] \neq 0$ (2.4)

$\Rightarrow$ A and B are ***not compatible***

Tutorial 2

1. Prove that for the operators A,B and C, the following identities are valid :

(i) $[A + B, C] = [A, C] + [B, C]$ (ii) $[A, BC] = [A, B]C + B[A, C]$

(iii) $[A, B + C] = [A, B] + [A, C]$ (iv) $[AB, C] = A[B, C] + [A, C]B$

2. One of the most important ***commutators*** in physics is that between the coordinate, $\hat{x}$, and the momentum, $\hat{p}$.

(i) Show that $[\hat{x}, \hat{p}] = i\hbar$

Hence,or otherwise,deduce that

(ii) $[\hat{x}^2, \hat{p}] = 2i\hbar\hat{x}$; (iii) $[\hat{x}, \hat{p}^2] = 2i\hbar\hat{p}$; (iv) $[\hat{H}, \hat{x}] = \frac{-i\hbar}{m}\hat{p}$;

(v) If g is an arbitrary function of x, show that $[\hat{p}, g] = -i\hbar\frac{dg}{dx}$