Clicker Questions

Review for Modern Physics Exam II

Mon, Oct 15
Question 1

A fast moving particle (particle 1) decays into two particles, with some angle $\theta$ between them. You want to use conservation of 4-momentum to find the angle between particle 1 and particle 3. The best equation to square is:

A. $\tilde{p}_1 = \tilde{p}_2 + \tilde{p}_3$
B. $\tilde{p}_2 = \tilde{p}_1 - \tilde{p}_3$
C. $\tilde{p}_3 = \tilde{p}_1 - \tilde{p}_2$
D. All of the Above
E. None of the Above

You'll obtain:

\[(m_2c)^2 = (m_1c)^2 + (m_3c)^2 - 2(E_1E_3/c^2 - p_1p_3 \cos \alpha)\]
Question 1

A fast moving particle (particle 1) decays into two particles, with some angle $\theta$ between them. You want to use conservation of 4-momentum to find the angle between particle 1 and particle 3. The best equation to square is:

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B $\vec{p}_2 = \vec{p}_1 - \vec{p}_3$
C $\vec{p}_3 = \vec{p}_1 - \vec{p}_2$
D All of the Above
E None of the Above

You’ll obtain:

$$(m_2c)^2 = (m_1c)^2 + (m_3c)^2 - 2(E_1E_3/c^2 - p_1p_3 \cos \alpha)$$

Where $\alpha$ is the angle you are after.
Question 2

What can we say about the positron and neutron at threshold in the process $p\bar{\nu}_e \rightarrow ne^+$?

A. They are produced at rest.
B. They are produced at rest in the center-of-momentum frame only.
C. They will have the same velocities in any frame.
D. B and C

In the CM frame: there is just enough neutrino energy to produce the extra mass required for the process to happen. Since the products have zero momentum in this frame they will have the same velocity if transformed to any other frame.
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In the CM frame: there is just enough neutrino energy to produce the extra mass required for the process to happen. Since the products have zero momentum in this frame they will have the same *velocity* if transformed to any other frame.
Consider $\hat{p}_f^2$, the square of the final momentum for some process.

A  We have to evaluate this in the same frame as $\hat{p}_i^2$.

B  We can evaluate it in any frame.
Consider \( \tilde{p}_f^2 \), the square of the final momentum for some process.  

A. We have to evaluate this in the same frame as \( \tilde{p}_i^2 \).  

B. We can evaluate it in any frame.  

It’s invariant!
When we do a calculation wherein we evaluate $\tilde{p}_i^2$ in one frame, and $\tilde{p}_f^2$ in another frame we are using:

A  Invariance
B  Conservation Laws
C  All of the Above
Question 4

When we do a calculation wherein we evaluate $\tilde{p}_i^2$ in one frame, and $\tilde{p}_f^2$ in another frame we are using:

A  Invariance
B  Conservation Laws
C  All of the Above

Conservation laws relate the initial and final states in the same frame.
Invariance relates a given state among different frames.
By combining them we can relate the initial state in one frame to the final state in another.
The Spectrum of Blackbody radiation is:
A  Invisible
B  Characterized by a single parameter
C  The cause of the expansion of the Universe
D  Really hot
E  All of the Above
Question 5

The Spectrum of Blackbody radiation is:
A  Invisible
B  Characterized by a single parameter
C  The cause of the expansion of the Universe
D  Really hot
E  All of the Above

The temperature characterizes the spectrum – all blackbodies with the same temperature radiate exactly the same way, it doesn’t matter what they are made of.
Electrons can be liberated from a metal with:

A. short enough wavelength light
B. long enough wavelength light
C. high enough intensity light
Question 6

Electrons can be liberated from a metal with:

A short enough wavelength light
B long enough wavelength light
C high enough intensity light

c = \lambda f, \ E = hf. Short wavelength (\lambda) means high frequency, and is therefore more energetic than long wavelength.
Question 7

In the photoelectric effect $\lambda_{\text{thresh}} = \frac{hc}{\phi}$, is this the

A minimum
B maximum

wavelength for electron emission to occur?
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A minimum

B maximum

wavelength for electron emission to occur?

Minimum energy $\rightarrow$ maximum wavelength ($E = \frac{hc}{\lambda}$).
Question 8

For $10^5$ eV electrons producing x-rays via bremmstrahlung, can we use $\frac{1}{2}m_e v^2$ to determine the kinetic energy of the electrons?

A  Yes

B  No
Question 8

For $10^5$ eV electrons producing x-rays via bremmstrahlung, can we use $\frac{1}{2}m_e v^2$ to determine the kinetic energy of the electrons?

A  Yes

B  No

\[
\begin{align*}
m_e c^2 &= 0.511 \text{ MeV} \\
\frac{KE}{m_e c^2} &= (\gamma - 1) \\
&\approx \frac{1}{5} \\
\Rightarrow \frac{v}{c} &\approx 0.55
\end{align*}
\]
We can use the Compton formula (or it’s equivalent by substituting for the mass of the stationary particle) for:

A. $\gamma p \rightarrow \gamma p$
B. $\gamma \gamma \rightarrow e^- e^+$
C. $\nu e \rightarrow \nu e$
D. All of the above
E. A and C
We can use the Compton formula (or it’s equivalent by substituting for the mass of the stationary particle) for:

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C. $\nu e \rightarrow \nu e$
D. All of the above
E. A and C

The analysis of Compton scattering involves an *elastic* collision between a massless particle and a stationary (massive!) one. For almost any scattering the neutrino mass can be taken as zero.
Question 10

We are given $\tilde{p}'_e$ for Compton Scattering and want to find $\tilde{p}_\lambda$. The usual thing is to write energy momentum conservation (in terms of 4-vectors) and then square them so that invariances simplify the calculation. Given that $\tilde{p}_\lambda + \tilde{p}_e = \tilde{p}'_\lambda + \tilde{p}'_e$, the best way to proceed is to square:

A $\tilde{p}'_\lambda = \tilde{p}_\lambda + \tilde{p}_e - \tilde{p}'_e$

B $\tilde{p}'_\lambda - \tilde{p}_e = \tilde{p}_\lambda - \tilde{p}'_e$

C either of the above

D none of the above
Question 10

We are given $\tilde{p}_e'$ for Compton Scattering and want to find $\tilde{p}_\lambda$. The usual thing is to write energy momentum conservation (in terms of 4-vectors) and then square them so that invariances simplify the calculation. Given that $\tilde{p}_\lambda + \tilde{p}_e = \tilde{p}_\lambda' + \tilde{p}_e'$, the best way to proceed is to square:

A. $\tilde{p}_\lambda' = \tilde{p}_\lambda + \tilde{p}_e - \tilde{p}_e'$
B. $\tilde{p}_\lambda' - \tilde{p}_e = \tilde{p}_\lambda - \tilde{p}_e'$
C. either of the above
D. none of the above

This eliminates the outgoing photon angle ($\theta$), and it’s energy, neither of which we need or want.
Question 11

With careful experiments you can measure a particle’s wavefunction.

A  True
B  False
With careful experiments you can measure a particle’s wavefunction.

A  True
B  False

Ψ is *not* observable
Ψ is *not* a physical wave
|Ψ|^2 *is* observable/physical
The plane wave

\[ \psi(x, t) = Ae^{i(kx-\omega t)} \]

represents a wave:

A Which is everywhere at once
B has a definite position
C might have any momentum
D none of the above
Question 12a

The plane wave

\[ \psi(x, t) = Ae^{i(kx-\omega t)} \]

represents a wave:

A. Which is everywhere at once
B. has a definite position
C. might have any momentum
D. none of the above

One has to think of \( k \) and \( \omega \) as parameters here, which have fixed values, while \( x \) and \( t \) are the dependent variables ranging from from \(-\infty \leftrightarrow \infty\).
Question 12b

The plane wave

$$\psi(x, t) = Ae^{i(kx - \omega t)}$$

represents a wave which:

A is stationary (not moving)
B moves left
C moves right
The plane wave

\[ \Psi(x, t) = Ae^{i(kx-\omega t)} \]

represents a wave which:

A  is stationary (not moving)
B  moves left
C  moves right

One way to this is to let \( t \rightarrow t + T \) where \( T = \frac{2\pi}{\omega} \) is the period, and then show that this is equivalent to shifting the entire pattern one wavelength to the right.

The relative minus sign in \( kx - \omega t \) is responsible for this.
Question 13

The plane wave

$$\psi(x, t) = Ae^{i(kx - \omega t)}$$

is not an eigenstate of:

A  energy
B  momentum
C  position
D  all of the above
Question 13

The plane wave

$$\psi(x, t) = Ae^{i(kx-\omega t)}$$

is not an eigenstate of:

A. energy
B. momentum
C. position
D. all of the above

You get the original $\psi$ back times a number if you operate on it with $\hat{p}$ or $\hat{E}$ but not if you do it with $\hat{x}$.

$$\hat{p}\psi = \frac{\hbar}{i} \frac{\partial}{\partial x} Ae^{i(kx-\omega t)}$$

$$= \frac{\hbar}{i} (ik) Ae^{i(kx-\omega t)}$$

$$= \hbar k \psi$$
Question 14

\[ \Psi(x, t) = Ae^{i(k_1 x - \omega_1 t)} + Be^{i(k_2 x - \omega_2 t)} \]

A has definite energy
B has definite momentum
C all of the above
D none of the above
Question 14

\[ \Psi(x, t) = Ae^{i(k_1 x - \omega_1 t)} + Be^{i(k_2 x - \omega_2 t)} \]

A. has definite energy  
B. has definite momentum  
C. all of the above  
D. none of the above

apply \( \hat{p} \) or \( \hat{E} \) to \( \Psi \) and you will not get a number multiplying the original \( \Psi \) (did this in HW).
Question 15

If $A_1 = 2A_2$ for the state

$$
\Psi(x, t) = A_1 e^{i(k_1 x - \omega_1 t)} + A_2 e^{i(k_2 x - \omega_2 t)}
$$

the probability that a momentum measurement (averaged over time or space) yields $\hbar k_1$ is:

A  $\frac{1}{5}$
B  $\frac{2}{5}$
C  $\frac{3}{5}$
D  $\frac{4}{5}$
E  1
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B $\frac{2}{5}$
C $\frac{3}{5}$
D $\frac{4}{5}$
E $1$

$$\frac{(2A_2)^2}{(2A_2)^2 + A_2^2} = \frac{4}{5}$$
Question 16

Is the plane wave eigenstate

$$\psi(x, t) = Ae^{i(kx-\omega t)}$$

normalizable:
A  Yes
B  No
Question 16

Is the plane wave eigenstate

\[ \psi(x, t) = A e^{i(kx - \omega t)} \]

normalizable:

A Yes

B No

\[
\int_{-\infty}^{\infty} (A e^{i(kx - \omega t)})^* (A e^{i(kx - \omega t)}) \, dx = A^2 \int_{-\infty}^{\infty} \, dx \\
= A^2 \times \infty \\
= \frac{1}{\sqrt{\infty}}
\]

is not that useful.
Question 17

Given an eigenfunction $\psi(x)$ of some Hamiltonian (the LHS of the Schrödinger equation), we can find the energy of the state it represents by applying the operator

A. $\hat{E}$
B. $\hat{p}$
C. All of the above
D. None of the above

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Given an eigenfunction $\psi(x)$ of some Hamiltonian (the LHS of the Schrödinger equation), we can find the energy of the state it represents by applying the operator

A $\hat{E}$
B $\hat{p}$
C All of the above
D None of the above

to $\psi(x)$.

$\hat{E} = i\hbar \frac{\partial}{\partial t}$ but $\frac{\partial}{\partial t} \psi(x) = 0$, always.
If $\psi_1(x)$ and $\psi_2(x)$ are solutions to a TISE, $\hat{H}\psi_n(x) = E_n\psi_n(x)$, then $\psi(x) = \psi_1(x) + \psi_2(x)$ is also a solution.

A  True  
B  False
If $\psi_1(x)$ and $\psi_2(x)$ are solutions to a TISE, $\hat{H}\psi_n(x) = E_n\psi_n(x)$, then $\psi(x) = \psi_1(x) + \psi_2(x)$ is also a solution.

A True
B False

$$\hat{H}\psi(x) = E_1\psi_1(x) + E_2\psi_2(x) \neq \# \times \psi(x)$$

but $\Psi(x, t) = \Psi_1(x, t) + \Psi_2(x, t)$ would be a solution to the TDSE, (we’d need to put the the time dependence in – will see how to do that later).
Question 19

An electron is confined to a box and the box is shrunk. The momentum of the electron:

A stays the same
B decreases
C increases
Question 19

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C increases

They get agitated when they are confined. An argument along these lines can be used to show that electrons from nuclear decay could not have pre-existed in the nucleus, but were created in the decay (given their typical energies the λ’s are “too long”).
Question 20

\[ \sigma_j = 0 \implies: \]
A. All of the values are zero
B. All of the values are the same
C. The sample size is zero
D. None of the above
σ_j = 0 ⇒:

A  All of the values are zero
B  All of the values are the same
C  The sample size is zero
D  None of the above

if \sqrt{\langle j^2 \rangle - \langle j \rangle^2} = 0 then every value equals the mean.
Question 21

How do you check if

$$\psi_n(x) = \begin{cases} \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L} & 0 \leq x \leq L \\ 0 & \text{otherwise} \end{cases}$$

is normalized?

A  $$\int_{-\infty}^{\infty} \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L} \, dx = 1$$

B  $$\int_{-\infty}^{\infty} \frac{2}{L} \sin^2 \frac{n\pi x}{L} \, dx = 1$$

C  $$\int_{0}^{L} \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L} \, dx = 1$$

D  $$\int_{0}^{L} \frac{2}{L} \sin^2 \frac{n\pi x}{L} \, dx = 1$$
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B \[ \int_{-\infty}^{\infty} \frac{2}{L} \sin^2 \frac{n\pi x}{L} \, dx = 1 \]

C \[ \int_{0}^{L} \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L} \, dx = 1 \]

D \[ \int_{0}^{L} \frac{2}{L} \sin^2 \frac{n\pi x}{L} \, dx = 1 \]

Integrate \( \psi^* \hat{x} \psi \). This \( \psi = 0 \) outside range \( 0 \leftrightarrow L \).
Question 22

How do you know $\langle p \rangle = 0$ for

$$\psi_n(x) = \begin{cases} \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L} & 0 \leq x \leq L \\ 0 & \text{otherwise} \end{cases}$$

without calculating it?

A  It’s a bound state
B  It would be imaginary otherwise
C  Symmetry
D  All of the above
E  None of the above
Question 22

How do you know $\langle p \rangle = 0$ for

$$\psi_n(x) = \begin{cases} \sqrt{\frac{2}{L}} \sin \left( \frac{n\pi x}{L} \right) & 0 \leq x \leq L \\ 0 & \text{otherwise} \end{cases}$$

without calculating it?

A  It’s a bound state  
B  It would be imaginary otherwise  
C  Symmetry  
D  All of the above  
E  None of the above

A: well not moving, B: $\frac{\hbar}{i} \times$ real stuff, C: no distinction between left and right (don’t really need for $\langle p \rangle$ but often useful for $\langle x \rangle$).
Normalize

\[ \psi(x) = \begin{cases} 
C & -\frac{w}{2} \leq x \leq \frac{w}{2} \\
0 & \text{otherwise}
\end{cases} \]

and you’ll get \( C =: \)

A \[ \frac{1}{\sqrt{w}} \]

B \[ \sqrt{w} \]

C \[ \frac{1}{w} \]

D \[ w \]
Question 23

Normalize

\[ \psi(x) = \begin{cases} 
C & -\frac{w}{2} \leq x \leq \frac{w}{2} \\
0 & \text{otherwise} 
\end{cases} \]

and you’ll get \( C =: \)

A \( \frac{1}{\sqrt{w}} \)

B \( \sqrt{w} \)

C \( \frac{1}{w} \)

D \( w \)

if this is multiple guess we don’t need to do the integral:

\[ 1 = C^2 \int_{-\frac{w}{2}}^{\frac{w}{2}} dx \]

because the 1D dimension for \( \psi(x) \) is *always* \( 1/\sqrt{\text{length}} \)
Question 24

From the spectral content of $\psi(x)$

$$A(k) = \frac{1}{\pi k \sqrt{w}} \sin \frac{kw}{2}$$

you can find:

A. momenta that will never be measured
B. the most probable momenta
C. All of the above
D. None of the above
Question 24

From the spectral content of $\psi(x)$

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B. the most probable momenta

C. All of the above

D. None of the above

A: find the zeros, B: find the maxima (largest peaks/deepest troughs) – this means taking derivatives

Remember: $p = \hbar k$, so $A(k)$ tells you about $p$. 
Suppose we have a wave function which is not an eigenstate of the quantity we want to measure. We make a measurement and obtain some value, say $\alpha$, for this quantity.

A we know that right before we made that measurement it had the value $\alpha$

B we don’t know that it had the value $\alpha$ right before we measured it
Suppose we have a wave function which is not an eigenstate of the quantity we want to measure. We make a measurement and obtain some value, say $\alpha$, for this quantity.

A. we know that right before we made that measurement it had the value $\alpha$.

B. we don’t know that it had the value $\alpha$ right before we measured it.

We don’t know – the value of $\alpha$ is indeterminate until it is measured. Theories that claim otherwise, “hidden variable theories” were considered to be viable for quite some time, but were experimentally excluded in the 80’s. (See EPR, Bell’s Theorem and Alain Aspect (1982) for more info).
Question 26

For the process $pp \rightarrow pp\bar{p}\bar{p}$ the initial 4-momentum in the Lab Frame – means one of the protons is at rest – can be written:

A $\left( E_1/c + m_pc, \vec{p}_1 \right)$
B $\left( \gamma_1 m_pc, \gamma_1 m\vec{v}_1 \right) + (m_pc, 0)$
C all of the above
D none of the above

where the incoming proton is identified by the subscript 1.
For the process $pp \rightarrow pp\bar{p}\bar{p}$ the initial 4-momentum in the Lab Frame – means one of the protons is at rest – can be written:

A $(E_1/c + m_pc, \vec{p}_1)$

B $(\gamma_1 m_pc, \gamma_1 m\vec{v}_1) + (m_pc, 0)$

C all of the above

D none of the above

but to calculate $\tilde{p}^2$ the most convenient way is probably a mixture of the two: $\tilde{p}_1 + \tilde{p}_2 = (E_1/c, \vec{p}_1) + (m_pc, 0)$

$\tilde{p}_i^2 = \tilde{p}_1^2 + \tilde{p}_2^2 + 2\tilde{p}_1 \cdot \tilde{p}_2$

$\tilde{p}_i^2 = 2(m_pc)^2 + 2E_1 m_p$
Question 27

For the FPSE: say \( \psi(x, t) = \cos(k_0 x - \omega_0 t) \). What momenta may be measured?

A \( \hbar k_0 \)

B \( -\hbar k_0 \)

C \( \hbar \omega_0 / c \)

D \( -\hbar \omega_0 / c \)

E 2 of the above
For the FPSE: say $\Psi(x, t) = \cos(k_0x - \omega_0 t)$. What momenta may be measured?

A $\hbar k_0$
B $-\hbar k_0$
C $\hbar \omega_0/c$
D $-\hbar \omega_0/c$
E 2 of the above

$\pm \hbar k_0$, $\hat{p} = -i\hbar \frac{\partial}{\partial x}$ can easily extract this after using the Euler relation $e^{i\theta} = \cos \theta + i \sin \theta$ to express $\cos \theta$ as plane waves, $\cos \theta = \frac{1}{2}(e^{i\theta} + e^{-i\theta})$, which are eigenstates of momentum given that $\theta = k_0x - \omega_0 t$ here.
Question 28

For the FPSE: say $\Psi(x, t) = \cos(k_0x - \omega_0 t)$. What else can be determined give $k_0$ and $\omega_0$?

A. the particle mass
B. the particle kinetic energy
C. the particle speed
D. all of the above

It's an eigenstate of $\hat{H}$ – the KE in this case, since we know we can get $p$ and $E$, we can get the rest (e.g. using $\hbar \omega = p^2 / 2m$, $p = mv$).
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It’s an eigenstate of \( \hat{H} \) – the KE in this case, since we know we can get \( p \) and \( E \), we can get the rest (e.g. using \( \hbar \omega = p^2/2m, p = mv \)).