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Obtaining subatomic particle sizes from creation-annihilation processes

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Abstract
A theoretical model to approximate subatomic particle sizes is proposed. The model draws inspiration from particle-antiparticle creation-annihilation processes. In the proposed model, collision of photons gives rise to particle-antiparticle pair with physical properties that the pair possesses: electric and magnetic properties arising from the electromagnetics of the photons, and the mass from the warping of the geometry of spacetime by the electromagnetic energy density of the photons. Results of the approximations of different particles' sizes are compared with experimental values and those obtained from other theoretical models.

Keywords: particle sizes, creation-annihilation, photons

1. Introduction

Mankind has always been fascinated by the nature of nature, the building blocks of matter and relationship between matter and waves. This consequently thrust science into the realms of atoms, particularly their properties and the laws governing them. The advent of particle physics unleashed particles from the zoo that were previously unimagined, with diverse properties. Among these properties is size. Different techniques have been used to obtain particle sizes. Experimental techniques include electron scattering [1], hydrogen spectroscopy [2] and muonic hydrogen spectroscopy [3]. Muonic hydrogen experiments have proven to yield more precise results and possibly more accurate. For instance, the earlier experiments like those of CODATA yielded a root-mean-square value of $\left\langle r^2 \right\rangle^{1/2} = 0.8768 \pm 0.0069$ fm for the proton radius [4], while more recent experiments that utilized muonic hydrogen spectroscopy have resulted in values of $\left\langle r^2 \right\rangle^{1/2} = 0.84184 \pm 0.00067$ fm [5]. Having the same charge as an electron, but more than 200 times heavier than the electron, a muon spends most of its time closer to the proton than its counterpart. This renders the energy levels of muonic hydrogen more sensitive to the proton radius than those of the hydrogen atom. Other experiments include a Zeus collaboration at HERA which yielded a upper limit on the effective quark radius of 0.43×10^{-18} m [1].

Theoretical investigations into the sizes of particles are not lagging behind either. Radii of baryons have been approximated by treating the interaction between any two quarks as simple harmonic-like [6]. Ananthanarayan *et al* determined the charge radius of a pion to be $\left\langle r^2 \right\rangle^{1/2} = 0.657 \pm 0.003$ fm [7]. The size of the weak boson has been hypothesized to be in the vicinity of 0.002 fm [8]. Yasser *et al* obtained root means square radius of Bottomonium from wave functions obtained utilizing Numerov's method [9]. Storti *et al* used electro-gravi-magnetics principle to approximate root mean square charge radii of a free electron, proton and a neutron [10]. Lenhert obtained a mass-radius relation which was then used to approximate sizes of the Z and the Higgs-like boson [11].

This study offers another approach of calculating radii of subatomic particles from particle-antiparticle annihilation-creation processes, and has the following organizational structure: Section 2 deals with the theoretical treatment of the problem. The results, analysis and discussion are found in Section 3 while the concluding remarks are laid in Section 4.

2. Theory

It is understood that a photon is a quantum of energy of an electromagnetic (EM) radiation, and the EM wave itself is a condition in spacetime where electric field (E) oscillates concomitantly with the associated magnetic field (B). When viewed at an instant time ($dt = 0$), there will be regions in space where E is in one direction ($\wp_-$) and in the opposite direction ($\wp_+$) in other regions. Suppose the colliding photons interact in such a way that $\wp_-$ and $\wp_+$ from both photons end up with the same kind from another photon, $\wp_\pm = \wp_{\pm1} + \wp_{\pm2}$ and get gravitationally bound into a photon ring. The resulting configurations can give rise to radially outgoing E, $\wp_+ = \wp_{+1} + \wp_{+2}$, and radially ingoing E, $\wp_- = \wp_{-1} + \wp_{-2}$, characteristic of the electric fields of a particle-antiparticle pair. Neutral particles emerge from portions of the photons that are of different senses: $\wp_0 = \wp_{\pm1} + \wp_{\mp2}$. The magnetic properties of charges emerge from magnetic components of the photons. The energy density of the photons warps the geometry of spacetime, which manifests as mass (m) of the particles and antiparticles. On this premise, if the two photons are to produce a particle and its antiparticle, then their energies must be sufficient to produce the particles with their masses. In addition, let us also imbue the photon ring with an angular momentum, rotating with angular velocity ω, which may possibly account for intrinsic particle spin (**S**) and helicity. In that case,

$$hf = mc^2 + mv^2/2 + I\,\omega^2/2 = mc'^2 + I\,\omega^2/2 \qquad (2.1)$$

where the moment of inertia $I = L/\omega = mR^2$ and $c'^2 = c^2 + v^2/2$. $hf = hc/\lambda$ is the energy of each photon, h being Planck's constant, f and λ are the frequency and wavelength of the colliding photon and v is the speed of the particle/antiparticle. We also impose a condition that the components of the photon rotate about a fixed point in such a way that the circumference of the orbit is an integer multiple of half a wavelength of the colliding photons:

$$\beta\frac{\lambda}{2} = 2\pi R\,, \qquad (2.2)$$

$$\Rightarrow \lambda = \frac{4\pi}{\beta}R \qquad (2.3)$$

where R is radius of the particle/Antiparticle. Using Eq. (2.3) in Eq. (2.1) yields a cubic equation in R;

$$\hbar c = \frac{mR}{\beta}\left(2c'^2 + R^2\omega^2\right) \qquad (2.4)$$

with solutions

$$R_0 = \frac{\gamma_0}{6m\omega} - \frac{4mc'^2}{\omega\gamma_0} \qquad (2.5)$$

and

$$R_\pm = \frac{2mc'^2}{\omega\gamma_0} - \frac{\gamma_0}{12m\omega} \pm \frac{i\sqrt{3}}{2}\left(\frac{\gamma_0}{6m\omega} + \frac{4mc'^2}{\omega\gamma_0}\right), \qquad (2.6)$$

where

$$\gamma_0 = \left\{\left(108\beta\hbar\omega + 12\sqrt{3}\sqrt{32m^2c'^2 + 27\beta^2\hbar^2\omega^2}\right)m^2c'\right\}^{1/3}. \qquad (2.7)$$

R_0 is real while $R_\pm$ are complex. Notwithstanding the fact that all the three solutions are mathematically equivalent as far as Eq. (2.4) is concerned, only the real solution, R_0, will be considered for physical reasons. The mass *m* of the particle in question can be evaluated using a number of ways. For example, the Schwinger nonet mass, Sakurai mass and the Gell-Mann-Okubo mass formulae [12] have been advanced. Buravov suggested a way of obtaining masses of particles by Considering a confining potential whose origins are recoil momentum at emission of specific virtual photons by the particle itself [13]. Masses of elementary particles have also been obtained by considering an electron as an electric cloud enshrouded inside an elastic lepton shell, the electron neutrino considered as an elastic lepton shell of minimal size, the muon, pion and kaon considered as resonators for quanta of virtual neutrinos excited inside the elastic lepton shell [14]. Additionally, a general relativized quantum theory has been suggested and generated masses of the bottom quark, top quark and charm quark [15]. It was also able to yield masses for W boson, Z boson and Higgs boson. However, for a more self-consistent approach, the mass should be electromagnetic [16],

$$m = 4\pi\varepsilon_0^2\mu_0\int_0^R r^2\rho(r)dr\,, \qquad (2.8)$$

where ε_0 and μ_0 are permittivity and permeability of free space respectively, and $\rho(r)$ is the electromagnetic energy density of the colliding photons. However, since this communication is not concerned with determination of masses of subatomic particles but rather their sizes, the values of the masses used in these calculations are measured (experimental) values listed in Appendix A.

3. Results and Discussions

The calculated particle radii listed in Table 1 have been generated using Eq (2.5) with $\beta = 1$ for bosons and $\beta = 8$ for baryons. The velocity v in Eq (2.1) accounts for the kinetic energy of the particle-antiparticle pair after creation process, and does not affect the critical energy needed to create a particle-antiparticle pair. For example, an externally applied electric field can be used to separate the particle from its antiparticle just after creation of the pair from photons of sufficient energy. Since the particle velocity only contributes to the kinetic portion of the energy and not to the creation process, the entries in Table 1 are for $v = 0$. However, in case one needs to consider a spontaneous separation of the particle-antiparticle pair, then the velocity must enable the particle–antiparticle pair to escape each other's Coulombic grasp: $mv^2/2 = kq^2/R$ or $v^2 = 2kq^2/mR$, which when inserted in Eq. (2.4) yields

$$\hbar c = \frac{mR}{\beta}\left(2c^2 + 2kq^2/mR + R^2\omega^2\right). \qquad (2.9)$$

Solution to Eq. (2.9) has the same functional form as for the $v = 0$ case, that is,

$$R_0 = \frac{\gamma_1}{6m\omega} - \frac{4mc^2}{\omega\gamma_1} \qquad (2.10)$$

and

$$R_{\pm} = \frac{2mc^2}{\omega\gamma_1} - \frac{\gamma_1}{12m\omega} \pm \frac{i\sqrt{3}}{2}\left(\frac{\gamma_1}{6m\omega} + \frac{4mc^2}{\omega\gamma_1}\right) \tag{2.11}$$

but with

$$\gamma_1 = \left\{m^2\left[108\omega\left(\beta\hbar c - kq^2\right) + 12\sqrt{3}\sqrt{32m^2c^6 + 27\beta^2\left(\hbar^2c^2 + k^2q^4\right) - 54\beta ckq^2\hbar\omega^2}\right]\right\}^{1/3}. \tag{2.12}$$

The dependence of particle radii on the angular velocity of the photon ring can be viewed in Fig. 1 for a few selected particles. The value of radius of a given particle decreases asymptotically with increasing angular velocity of the photon ring. The dots (in Fig. 1) indicate the angular frequencies corresponding to the quantized intrinsic spins of the particles. This implies that $\omega = 0$ gives the upper bound of *R*, which is what has been displayed in Table 1.

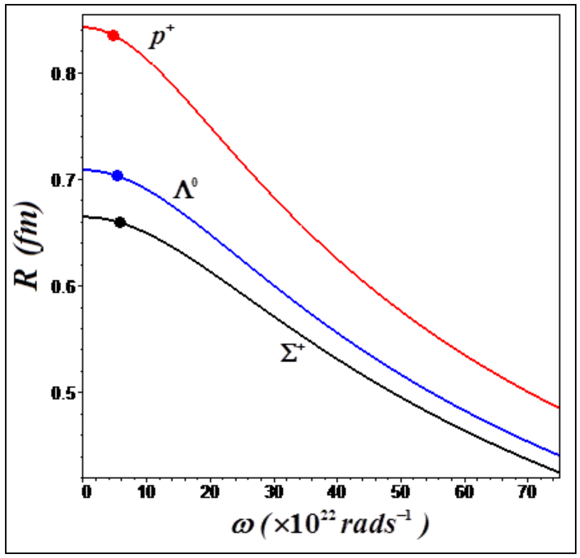

Fig 1: The dependence of particle radius on the angular velocity of rotation of the photon ring for selected particles

Table 1: Comparison between radii of particles calculated using the method outlined herein and other values obtained from experiments (MV-measured value) and/or from other theoretical models (TV-theoretical value). Here, R ≡ radius, CR ≡ charge radius, MR ≡ magnetic radius, ER ≡ electric radius.

Particle	Calculated radius (*fm*)	Radius from literature (*fm*)	% Deviation
Proton (p^+)	0.8412356674	0.8418467 [5] (MV)R	0.07
		0.8408739 [3] (MV)CR	0.04
Neutron (n^0)	0.8400776879	$0.8640^{+0.0009}_{-0.0008}$ [17] (MV)MR	2.77
Charged sigma (Σ^+)	0.6636353197	0.7733821824 [18] (TV)ER	14.19
		0.7861297603 [18] (TV)ER	15.58
Charged sigma (Σ^-)	0.6591578766	0.78 ± 0.10 [19] (MV)CR	15.49
		0.6438167441 [18] (TV)ER	2.38
		0.6730527468 [18] (TV)ER	2.06
Neutral sigma (Σ^0)	0.6618146436	0.79 ± 0.02 [6] (TV)R	16.22
Charged xi (Ξ^-)	0.5971869322	0.5674504384 [20] (TV)	5.24
		0.5935486501 [18] (TV)ER	0.61
		0.6099180273 [18] (TV)ER	2.09
Neutral xi (Ξ^0)	0.6002980851	0.73 ± 0.02 [6] (TV)R	17.77
Charged omega (Ω^-)	0.4719471077	0.68 ± 0.02 [6] (TV)R	30.60
Neutral delta (Δ^0)	0.6406720294	0.83 ± 0.02 [6] (TV)R	22.81
Neutral lambda (Λ^0)	0.7074661352	0.79 ± 0.02 [6] (TV)R	10.45
Charged pion ($\pi^{+/-}$)	0.7069073678	0.657 ± 0.003 [7] (MV)CR	7.60
		0.672 ± 0.008 [19] CR	5.20
Neutral pion (π^0)	0.7309652202	–	–
Higgs-Boson (*H*)	$0.7886769986 \times 10^{-3}$	$(0.54 - 1.5) \times 10^{-3}$ [11] (MV)	–
Z-Boson (*Z*)	$1.081983653 \times 10^{-3}$	$(0.87 - 2.2) \times 10^{-3}$ [11] (MV)	–
W-Boson (*W*)	$1.227478477 \times 10^{-3}$	$(1 - 2) \times 10^{-3}$ [8] (MV)	–

It is observed that generally Eq. (2.7) yields values comparable to measured values and those obtained from other theoretical models. This intuitively prompts a need for further investigation into the ramifications of this model, for there seems to be a bit more intimate relationship between matter and photons. This is further strengthened by the following fact. For a charged particle to move undeviated in a cross-field arrangement, the charged particle must have velocity in a specific direction and having a specific magnitude $v_{crit} = E/B$, where E and B are the amplitudes of the electric and magnetic fields of the cross field system. Now, the velocity of the photon also is in the right direction, and has the critical magnitude $v_{crit} = c$, relative to the electric and magnetic oscillations it has.

4. Conclusions

Sizes of subatomic particles have been approximated by considering particle-antiparticle creation-annihilation process. In the model, a collision of two photons of sufficient energy results in regions of spacetime wherein electric field line radiates outwards (corresponding to a positive particle/antiparticle) and another region wherein the electric field lines converge to a point (characteristic of a negative particle/antiparticle). Neutral particles emerge from regions of spacetime where the electric fields from the two photons oppose each other, such that the net electric flux is zero. The newly coupled configurations of electric and magnetic fields, being energy, warp the geometry of spacetime in a way that gravitationally traps the configurations, resulting in a ring of these electromagnetic fields orbiting each other at the speed of light. The size of subatomic particles was then obtained by requiring that the wavelength (precisely, half the wavelength) of the photons be an integer multiple of the circumference of the photon sphere. Here, mass then arises from the deformation of the geometry of spacetime due to the photon ring.

Table A1: Values for particle masses used in these computations

Particle	Mass (MeV)
Proton (p^+)	$938.2720813 \pm 0.00000058$ [21]
Neutron (n^0)	$939.5654133 \pm 0.00000058$ [21]
Charged sigma (Σ^+)	1189.37 ± 0.07 [21]
Charged sigma (Σ^-)	1197.449 ± 0.030 [21]
Neutral sigma (Σ^0)	1192.642 ± 0.024 [21]
Charged xi (Ξ^-)	1321.71 ± 0.07 [21]
Neutral xi (Ξ^0)	1314.86 ± 0.20 [21]
Charged omega (Ω^-)	1672.45 ± 0.21 [21]
Neutral delta (Δ^0)	1232 [19]
Neutral lambda (Λ^0)	1115.683 ± 0.006 [21]
Charged pion ($\pi^{+/-}$)	139.57061 ± 0.00024 [21]
Neutral pion (π^0)	134.9770 ± 0.0005 [21]
Higgs-Boson (*H*)	125100 ± 140 [21]
Z-Boson (*Z*)	91187.6 ± 2.1 [21]
W-Boson (*W*)	80379 ± 12 [21]

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