Light into matter

Oliver Pike explains to *Nature Photonics* that the so far elusive electron–positron pair production from light may now be possible using existing technology.

Why work on Breit–Wheeler pair production?

The Breit–Wheeler process is the production of an electron–positron pair from the collision of two photons. Being the inverse of Dirac annihilation, it is the simplest mechanism by which light can be converted into matter. The process also has wide significance for areas of high-energy astrophysics, including the radiation fields of compact objects, the cut-off of cosmic rays propagating over intergalactic distances and the various mechanisms of gamma-ray burst emission. We have long been interested in the physics of such systems and approaches for replicating their behaviour in the laboratory. When we performed order-of-magnitude estimates to assess how existing laser facilities could be used to study the fundamental processes relevant to these systems, we were surprised to discover that Breit–Wheeler pair production may finally be observable 80 years after it was theoretically predicted.

How can pair production be done in the laboratory?

Detecting the Breit–Wheeler process has proved extremely difficult, because of the high energy threshold for the reaction: the product of the two photon energies must be at least $(511 \text{ keV})^2$. In the past, this requirement has been too demanding, and consequently the process has completely eluded observation. By using a unique combination of gamma- and X-ray sources, our scheme is the first capable of promoting a sufficient number of photons above the threshold.

First, electrons are accelerated to ultrarelativistic energies using, for example, a laser wakefield. These are converted into an intense gamma-ray beam (0.1–1 GeV) through their bremsstrahlung emission in solid gold. The beam is then fired into the thermal radiation (with temperatures of ~100 eV) of a laser-heated hohlraum. These radiation fields typically have very high photon number densities, resulting in a significant probability of scattering with the gamma-ray beam. The electrons and positrons emerging from the back of the gold are deflected using a magnetic field to prevent them from entering the hohlraum; the photon–photon collisions occur in vacuum. In other words, this experiment would be the first in which light interacts with itself with no massive particles present.

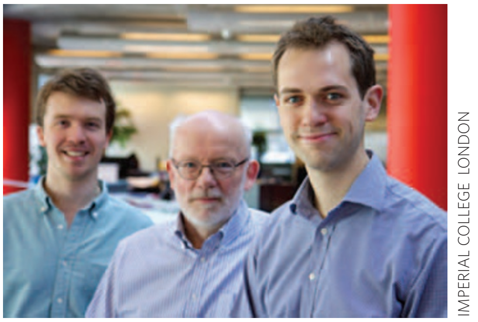
Where should the experiment be conducted?

We have tailored the scheme for specific laser facilities. The experiment is well suited to those where hohlraum experiments are performed, such as the National Ignition Facility (NIF), Omega EP and the Orion laser; these facilities have highly energetic long-pulse systems and will soon (after the imminent commissioning of the ARC system at NIF) all have powerful short-pulse capabilities. However, the experiment could also be performed at much smaller optical laser facilities, such as Astra Gemini and the Berkeley Lab Laser Accelerator, which are routinely used to produce high-quality wakefields. In this case, the hohlraum radiation could be replaced by X-ray fields created by laser irradiation of solid targets; these fields can be both energetic and intense even for relatively low laser energies when short pulse lengths are used. Finally, free-electron laser facilities, such as the Linac Coherent Light Source, could also host a variant of this experiment in which the X-ray beam acts as the second source of photons.

What is the expected performance of pair production?

The number of Breit–Wheeler pairs produced depends on the system used. The combination of a leading ultrashort pulse system (for example, Astra Gemini) and the largest long-pulse system (NIF) would yield about 10^5 pairs per shot. As they exist today, the coupled long- and short-pulse facilities are capable of producing between 10^3 and 10^4 Breit–Wheeler pairs per shot. Smaller optical and free-electron laser facilities are likely to give lower per-shot yields of between one and ten, but they benefit from higher repetition rates.

Detection of Breit–Wheeler pairs is greatly helped by both their narrow collimation (1–10 mrad) and high energies (0.1–1 GeV). In our view, the most effective detection method would be to use a magnetic field to isolate the positrons, and then use Čerenkov glass in combination with an intensified CCD (charge-coupled device) to collect their signature radiation.



Ed Hill, Steve Rose and Oliver Pike (left to right) with Felix Mackenroth (not pictured) have proposed a way to use existing facilities to produce electron–positron pairs by colliding photons.

Are the implications only fundamental, or are they also applied?

The primary motivation behind this work is the first-time detection of a fundamental physical process. In addition, successfully implementing the experiment would represent the first two-photon collider, which may ignite interest in the concept in the high-energy-physics community. As with any pure-science experiment, it may lead to further applications, but at this stage these remain unclear.

What plans do you have for future research?

We are actively pursuing options to collaborate with various laboratories to perform the experiment. As the applicability of our scheme is fairly general, and its set-up is seemingly robust, we are hopeful that Breit–Wheeler pair production will soon become the latest of the fundamental linear quantum electrodynamics processes to be observed.

INTERVIEW BY DAVID PILE

Oliver Pike and co-workers have a Letter on their proposed photon–photon collider on page 434 of this issue.