Giant Rydberg excitons in the copper oxide Cu_2O

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Nature **514**, 343–347 (2014). doi:10.1038/nature13832

Oct 25, 2014

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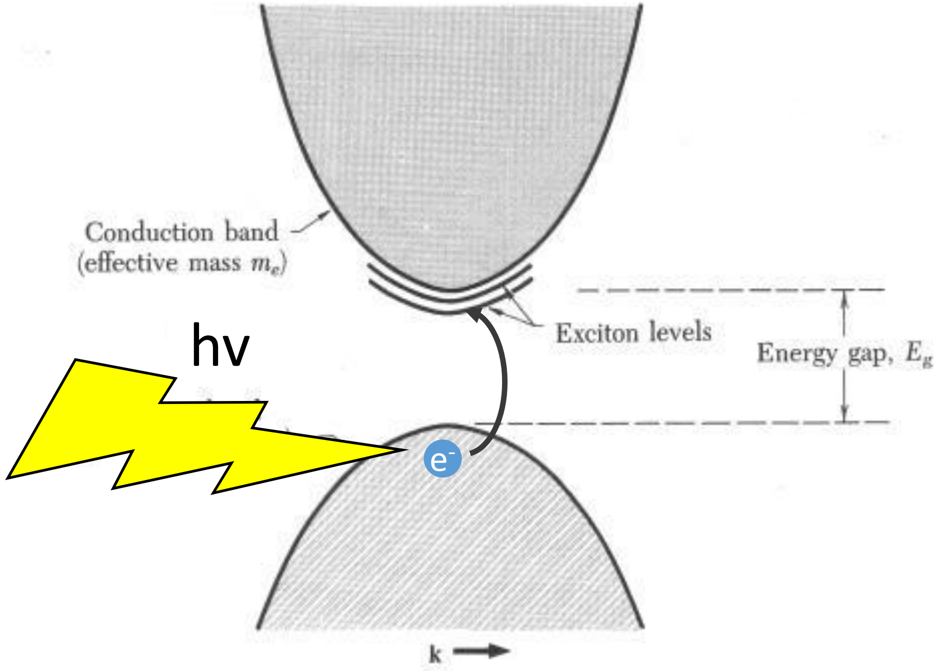
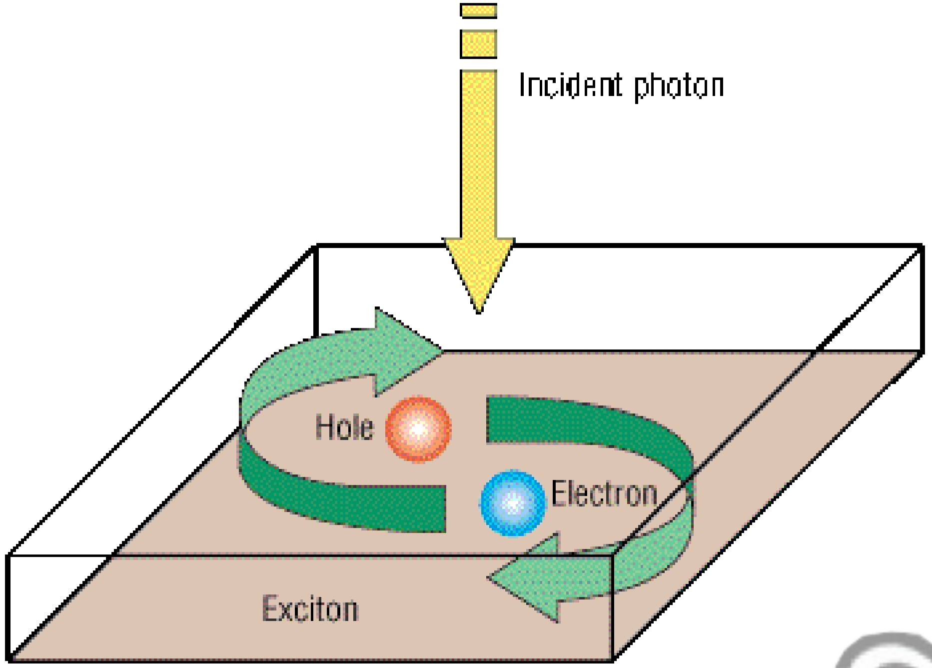
Introduction – Excitons

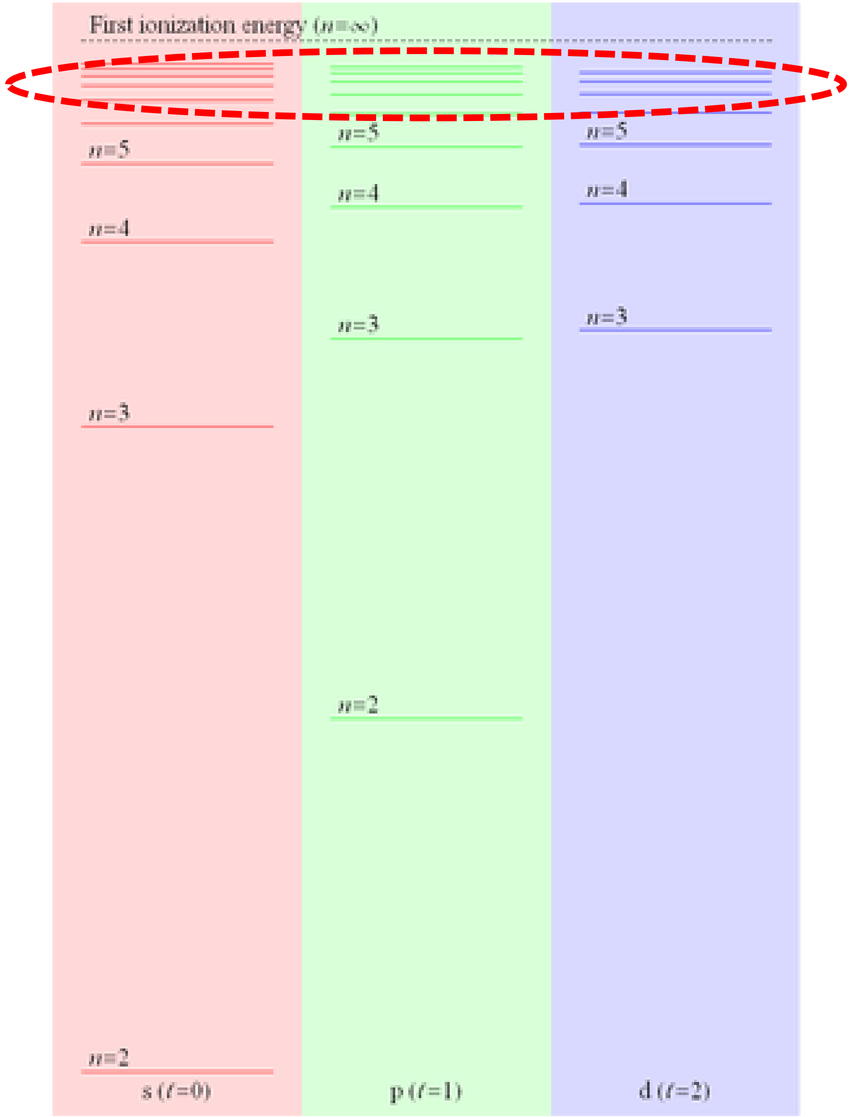




An **exciton** is a <u>bound state of an electron and an electron hole</u> which are attracted to each other by the electrostatic Coulomb force.

➡ **Quasi-particle** : condensed-matter analogue of <u>hydrogen atom</u>

Introduction - Rydberg atoms

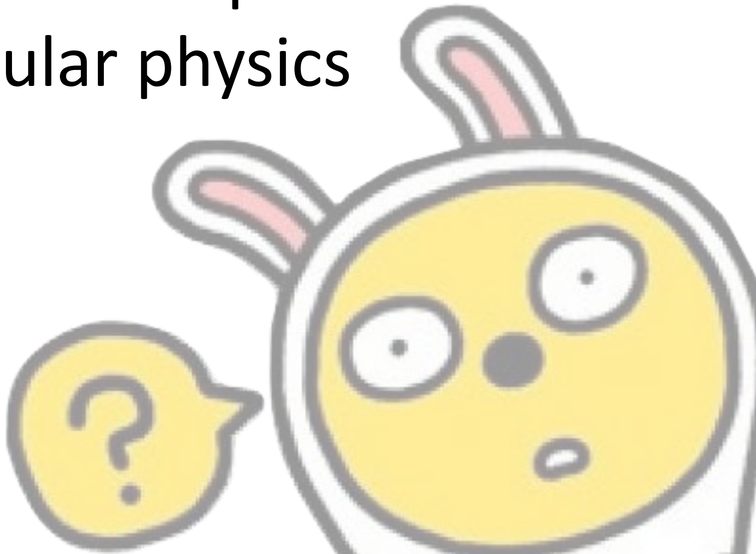


http://en.wikipedia.org/wiki/Rydberg_atom

A **Rydberg atom** is an excited atom with one or more electrons that have a *very high* principal quantum number (n).

➡ Hydrogen-like object

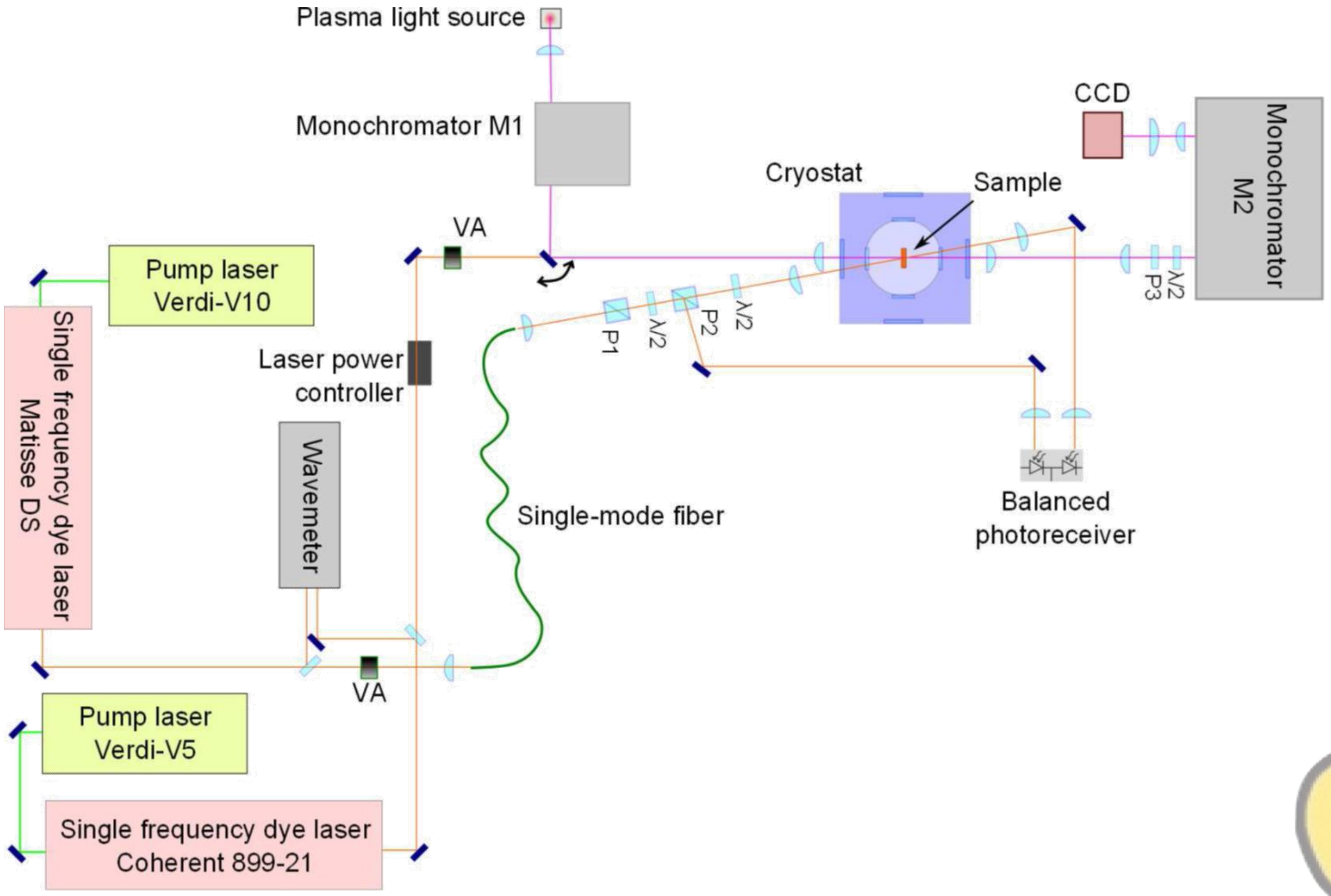
Rydberg atom typically has giant size ($\propto n^2$) and huge interaction effect – which provided insights into atomic & molecular physics



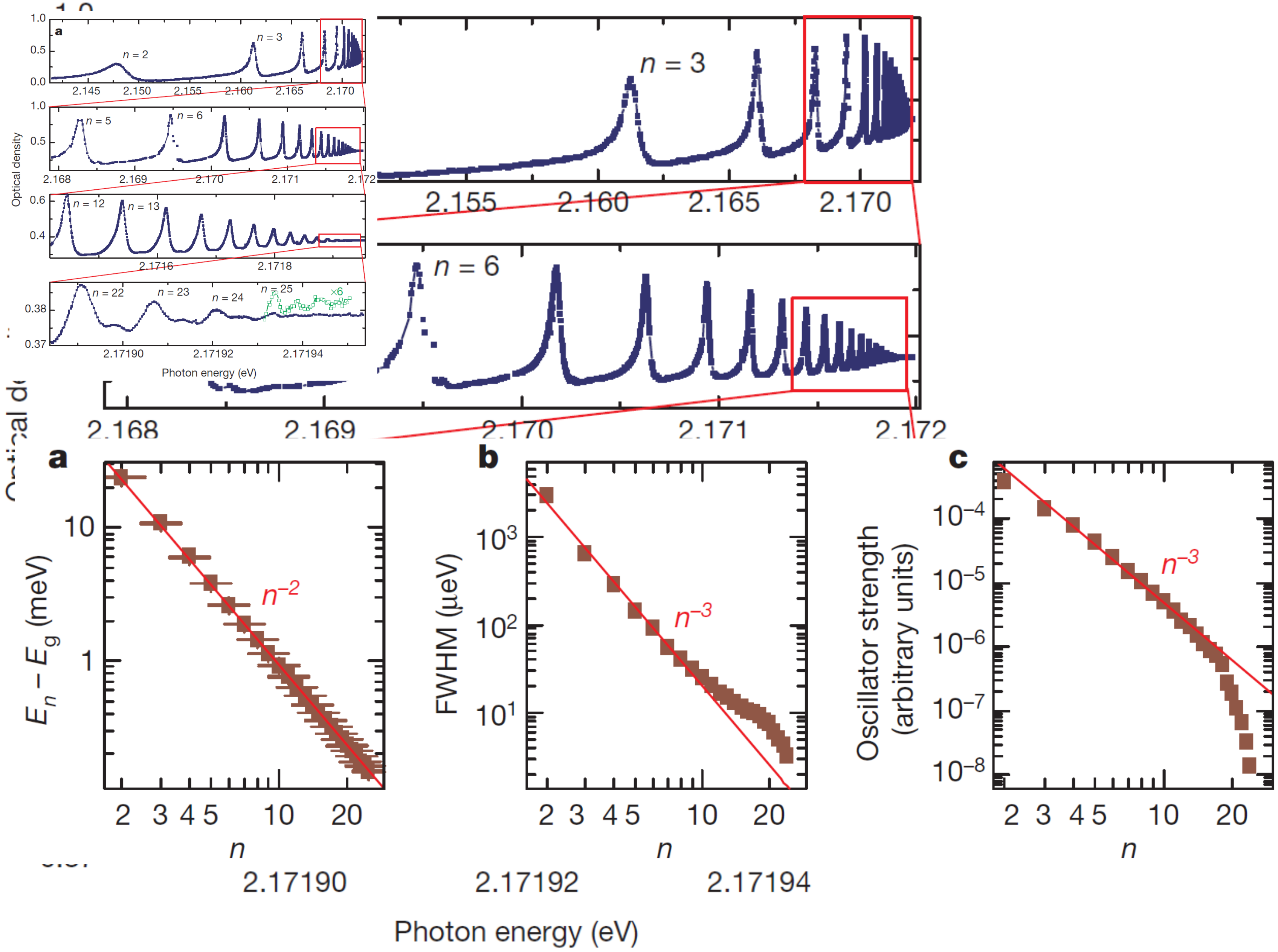
Abstract

A highly excited atom having an electron that has moved into a level with large principal quantum number is a hydrogen-like object, termed a Rydberg atom. The giant size of Rydberg atoms[1] leads to huge interaction effects. Monitoring these interactions has provided insights into atomic and molecular physics on the single-quantum level. Excitons—the fundamental optical excitations in semiconductors[2], consisting of an electron and a positively charged hole—are the condensed-matter analogues of hydrogen. Highly excited excitons with extensions similar to those of Rydberg atoms are of interest because they can be placed and moved in a crystal with high precision using microscopic energy potential landscapes. The interaction of such Rydberg excitons may allow the formation of ordered exciton phases or the sensing of elementary excitations in their surroundings on a quantum level. Here we demonstrate the existence of Rydberg excitons in the copper oxide Cu_2O, with principal quantum numbers as large as $n = 25$. These states have giant wavefunction extensions (that is, the average distance between the electron and the hole) of more than two micrometres, compared to about a nanometre for the ground state. The strong dipole–dipole interaction between such excitons is indicated by a blockade effect in which the presence of one exciton prevents the excitation of another in its vicinity.

Experimental scheme

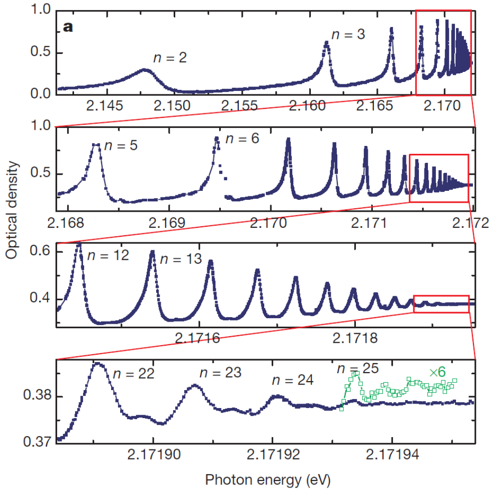


Result

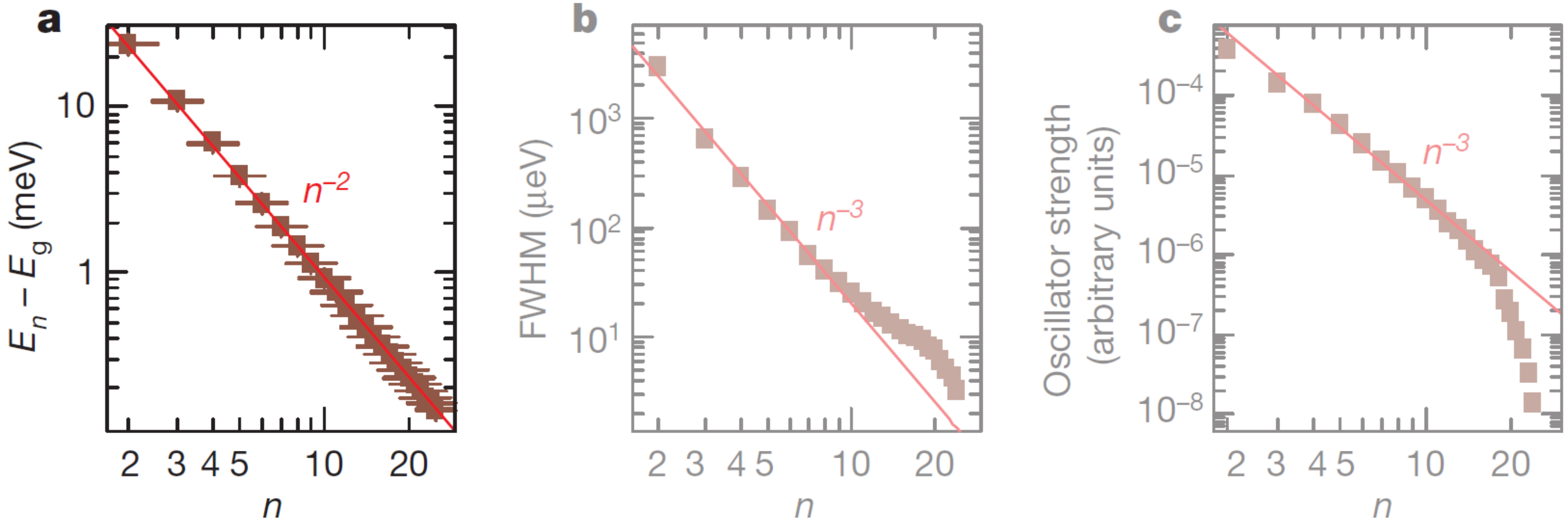


a
n = 2
n = 3
n = 5
n = 6
n = 12
n = 13
n = 22
n = 23
n = 24
n = 25
×6
Optical density
Photon energy (eV)
2.155
2.160
2.165
2.170
2.168
2.169
2.170
2.171
2.172
b
c
$E_n - E_g$ (meV)
FWHM (μeV)
Oscillator strength (arbitrary units)
n^{-2}
n^{-3}
n^{-3}
n
2.17190
2.17192
2.17194

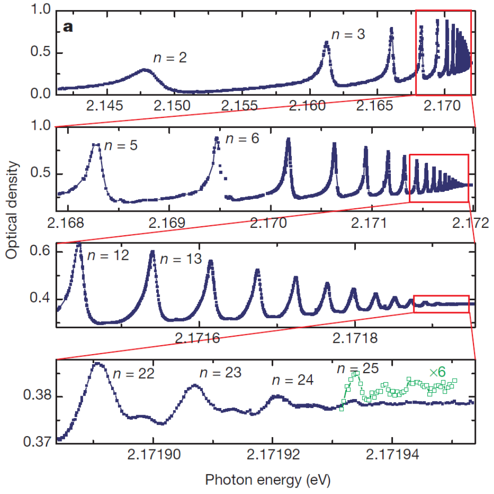
Result



1. Exciton binding energy: $E_n - E_g = \frac{\text{Ry}}{n^2}$

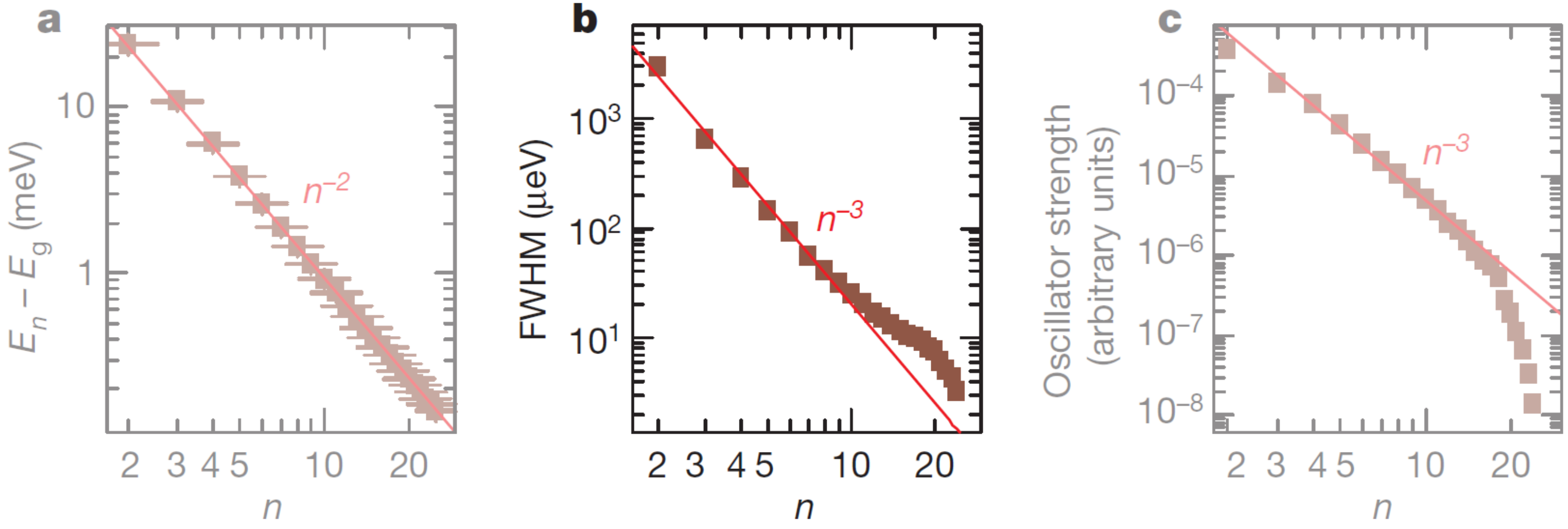


Result



2. Linewidth : $$\Gamma_n \propto \frac{1}{n^3}$$

Ref. Toyozawa, Y., *Prog. Theor. Phys.* **20**, 53-81 (1958)



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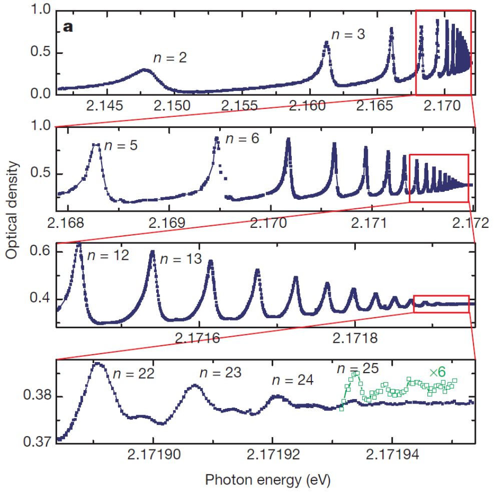
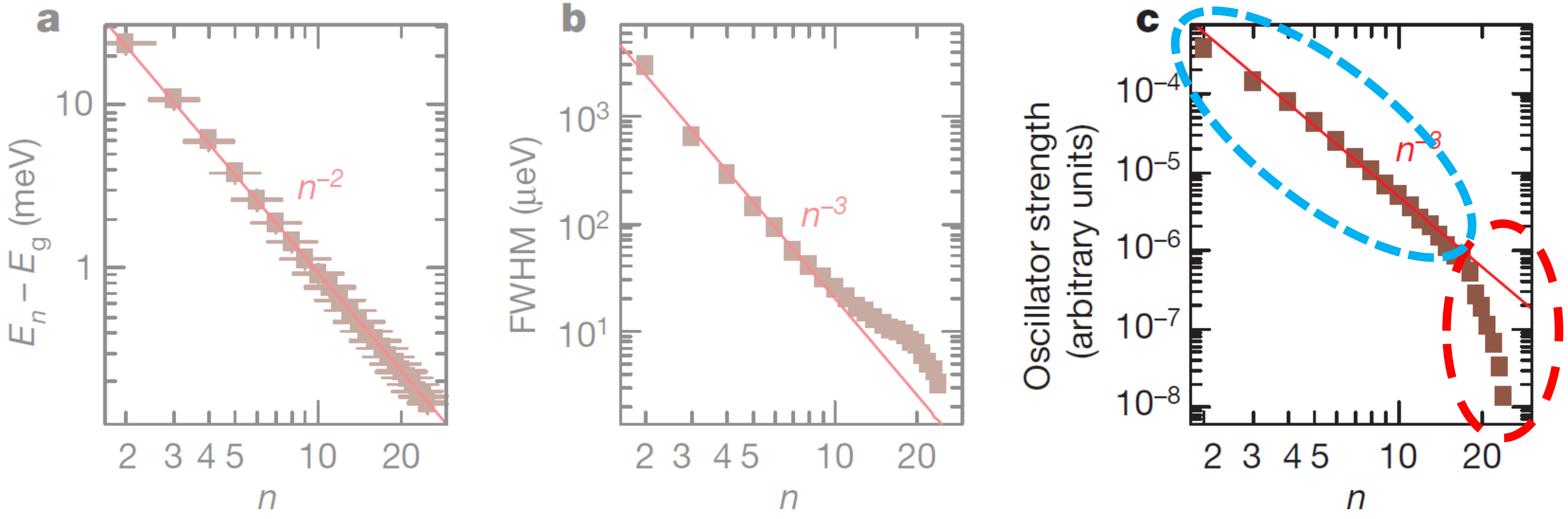
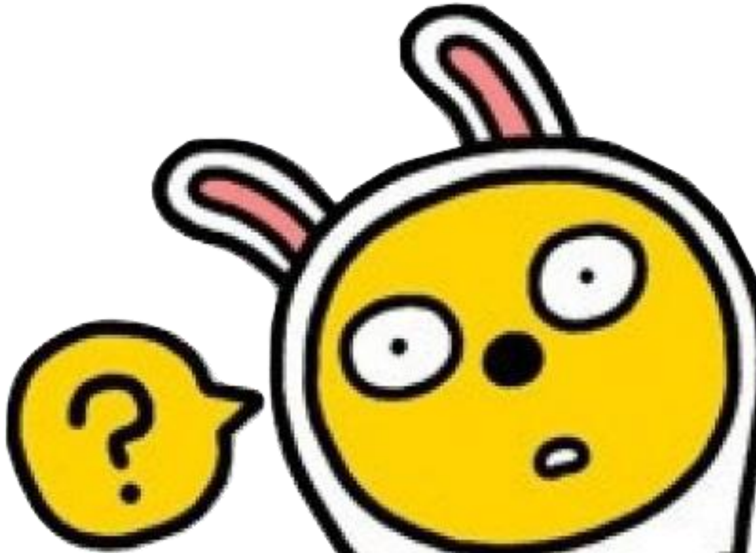


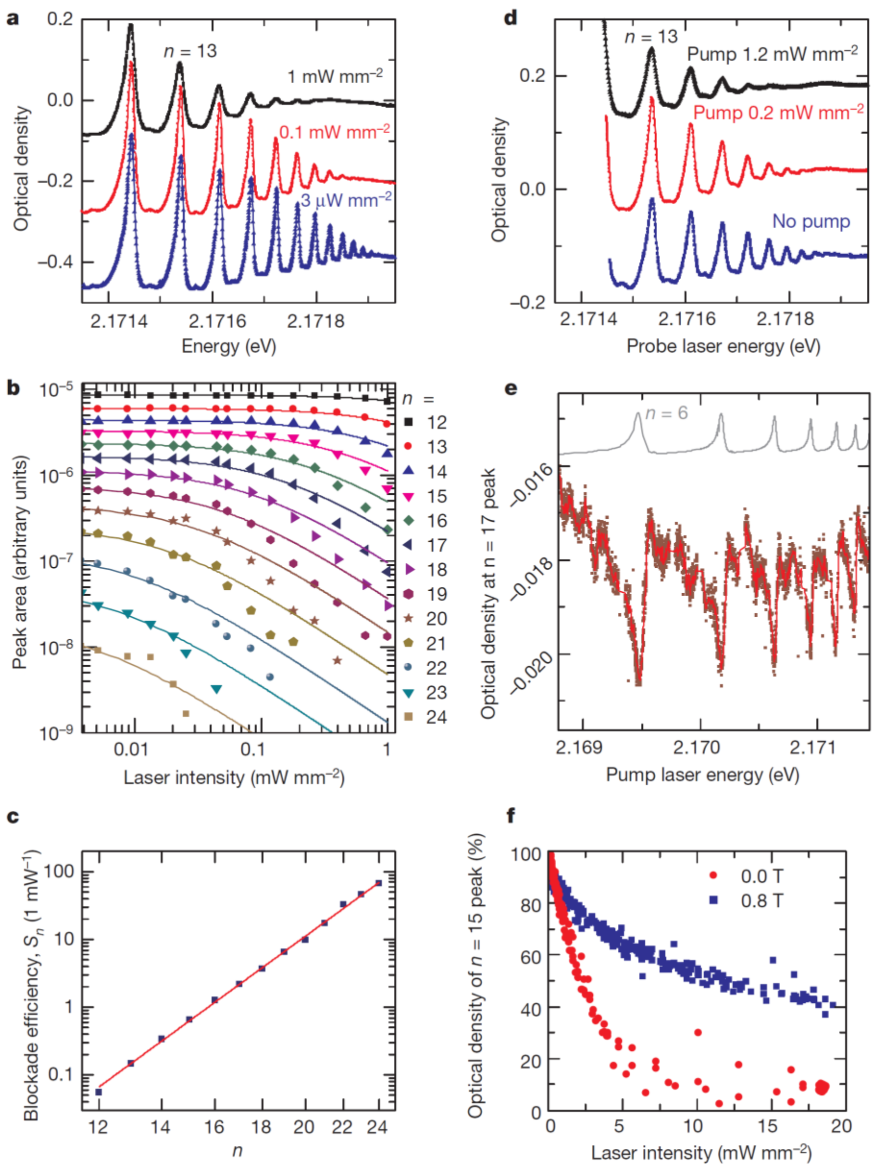
3. Oscillator strength : the area of each absorption peaks

$$\propto \frac{n^2 - 1}{n^5} \sim \frac{1}{n^3}$$





Exciton blockade effect



Conclusion

Giant Rydberg excitons having as large principal quantum number as n=25 were demonstrated in the copper oxide crystal

Energy and width of exciton absorption spectrum well followed the theoretical prediction, the oscillator strength seems to be saturated for high n’s – which is explained by *exciton blockade effect*.