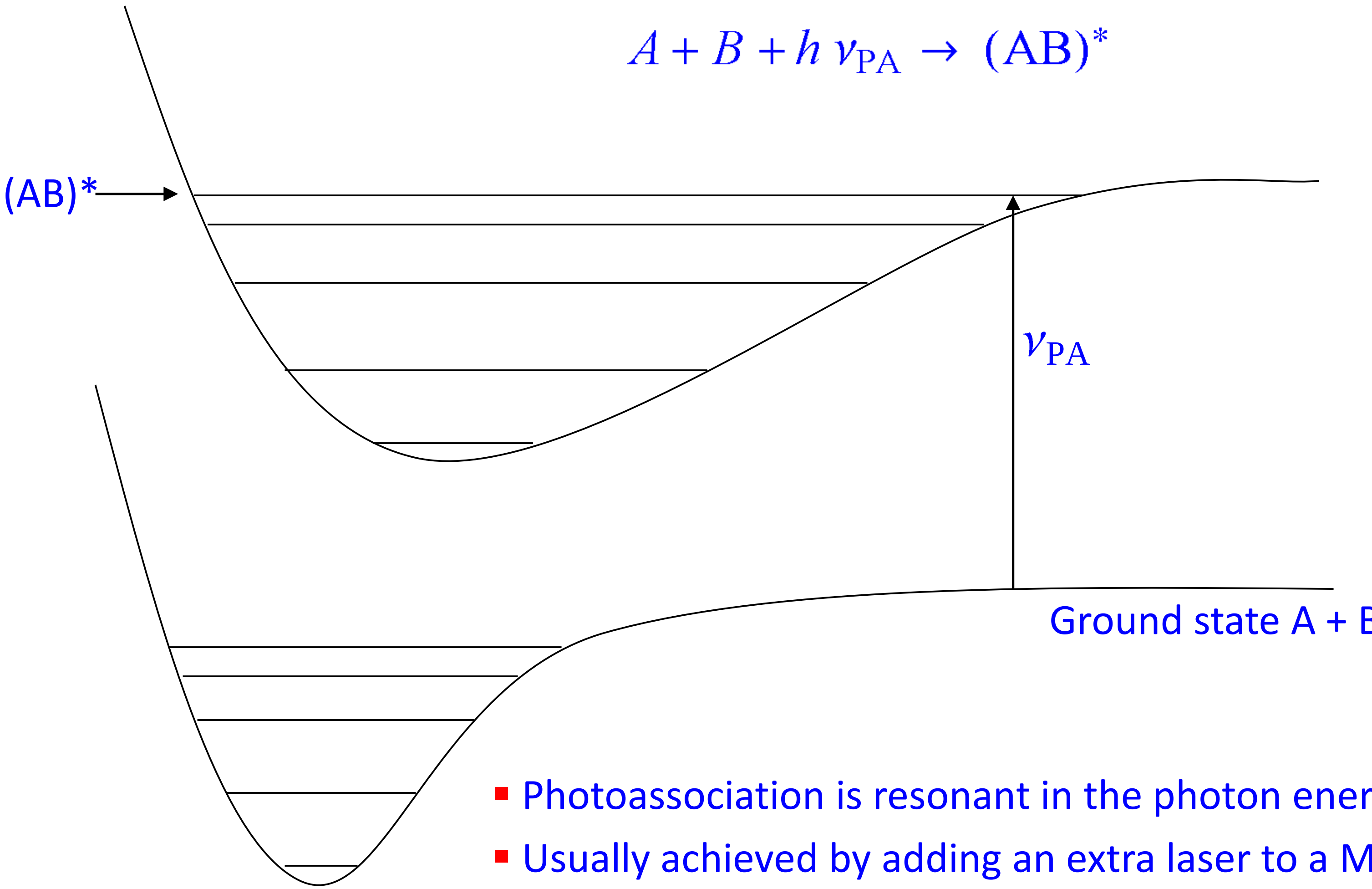
Making cold molecules from cold atoms

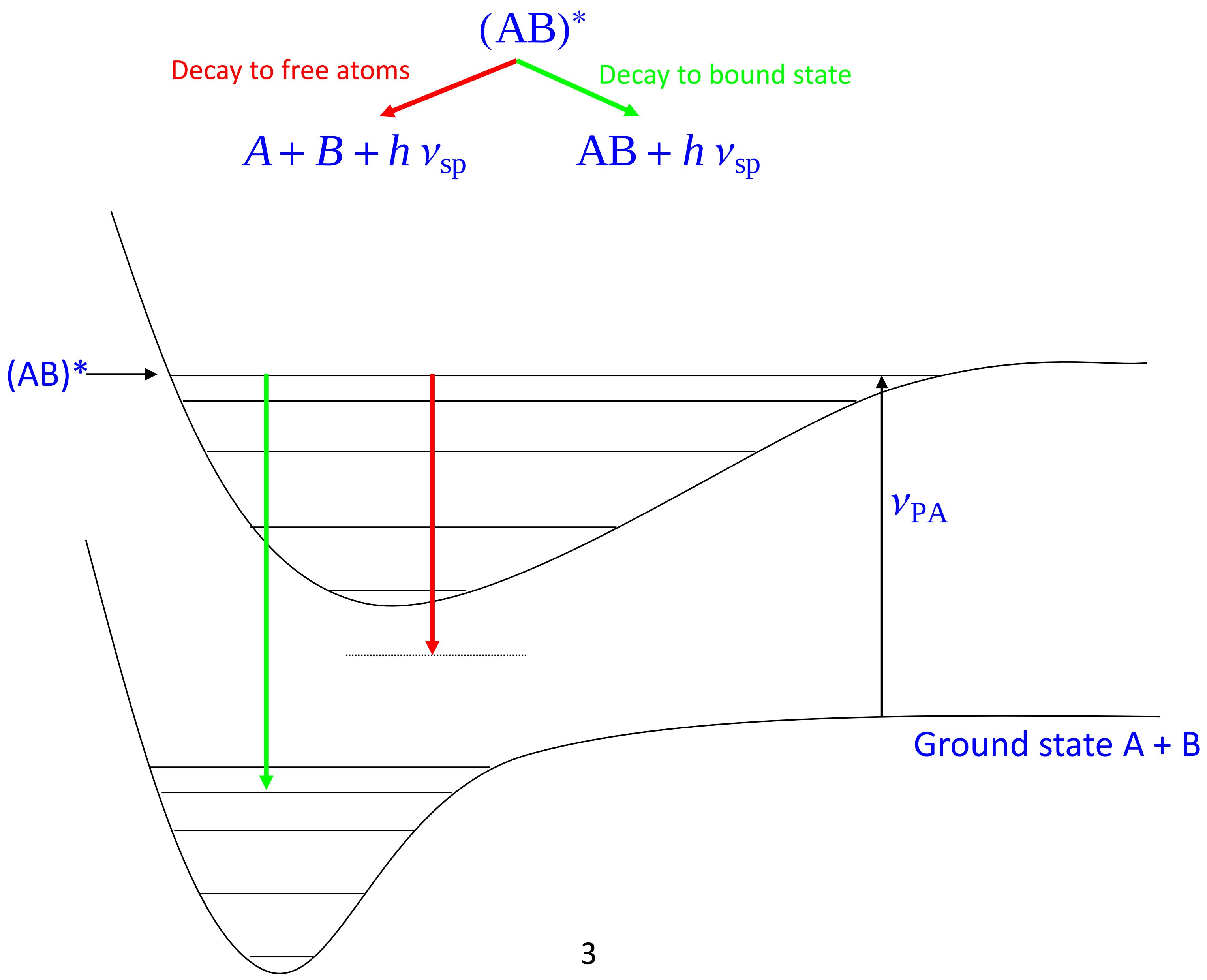
Photoassociation

$$A + B + h\,\nu_{PA} \rightarrow (AB)^*$$

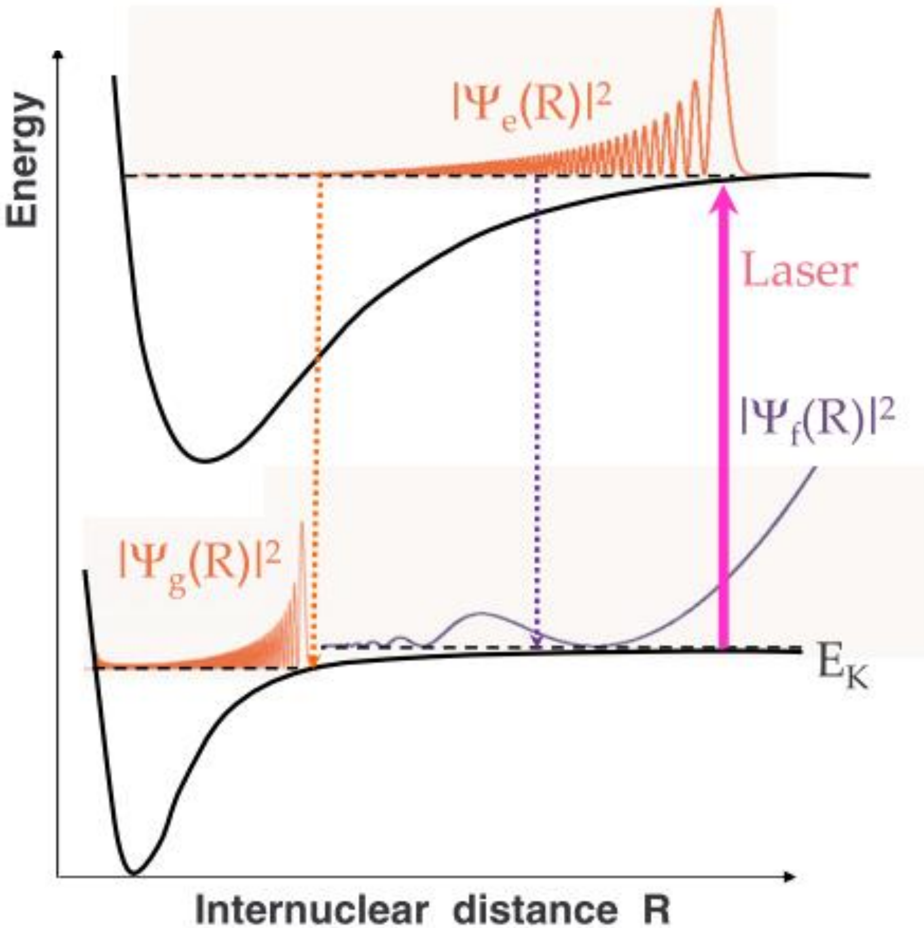


- Photoassociation is resonant in the photon energy
- Usually achieved by adding an extra laser to a MOT – the PA laser
- Very little heating involved – the molecules are ultracold
- Molecules will be in low-lying rotational states
- Produces molecules in highly excited vibrational states

Photoassociation – decay channels



Photoassociation properties



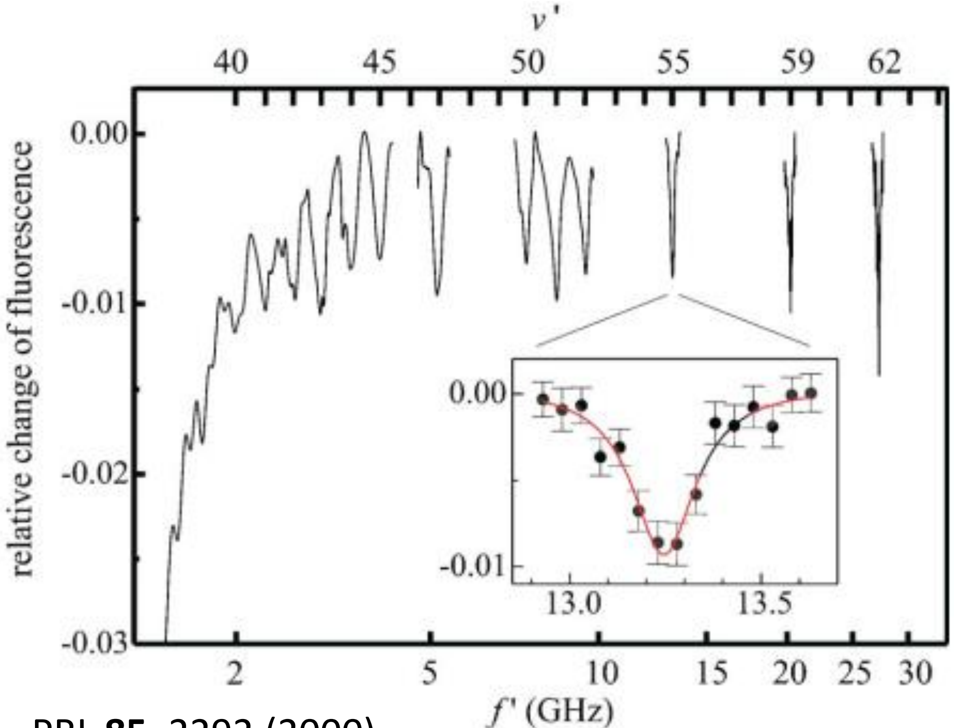
- Occurs at outer turning point of excited vibrational state
- Extremely inefficient for tightly bound states – tend to form “long-range molecules”
- Decay to a deeply bound state of the molecular ground state is unlikely
- Decay to two free atoms is accompanied by a large release of energy – trap loss

Li_2, Na_2, K_2, Rb_2, Cs_2, Sr_2 , Ca_2 , LiCs....

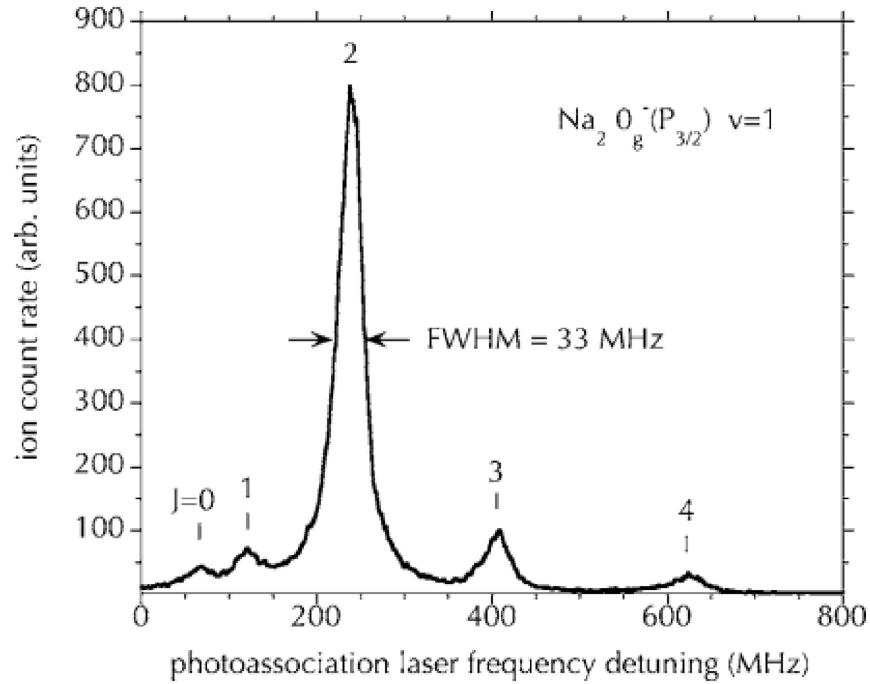
Detection methods

Trap loss spectroscopy – the number of atoms in a MOT decreases when the molecules are formed. Example below: Ca_2

Ion detection. Ionize the molecules and count the ions produced.

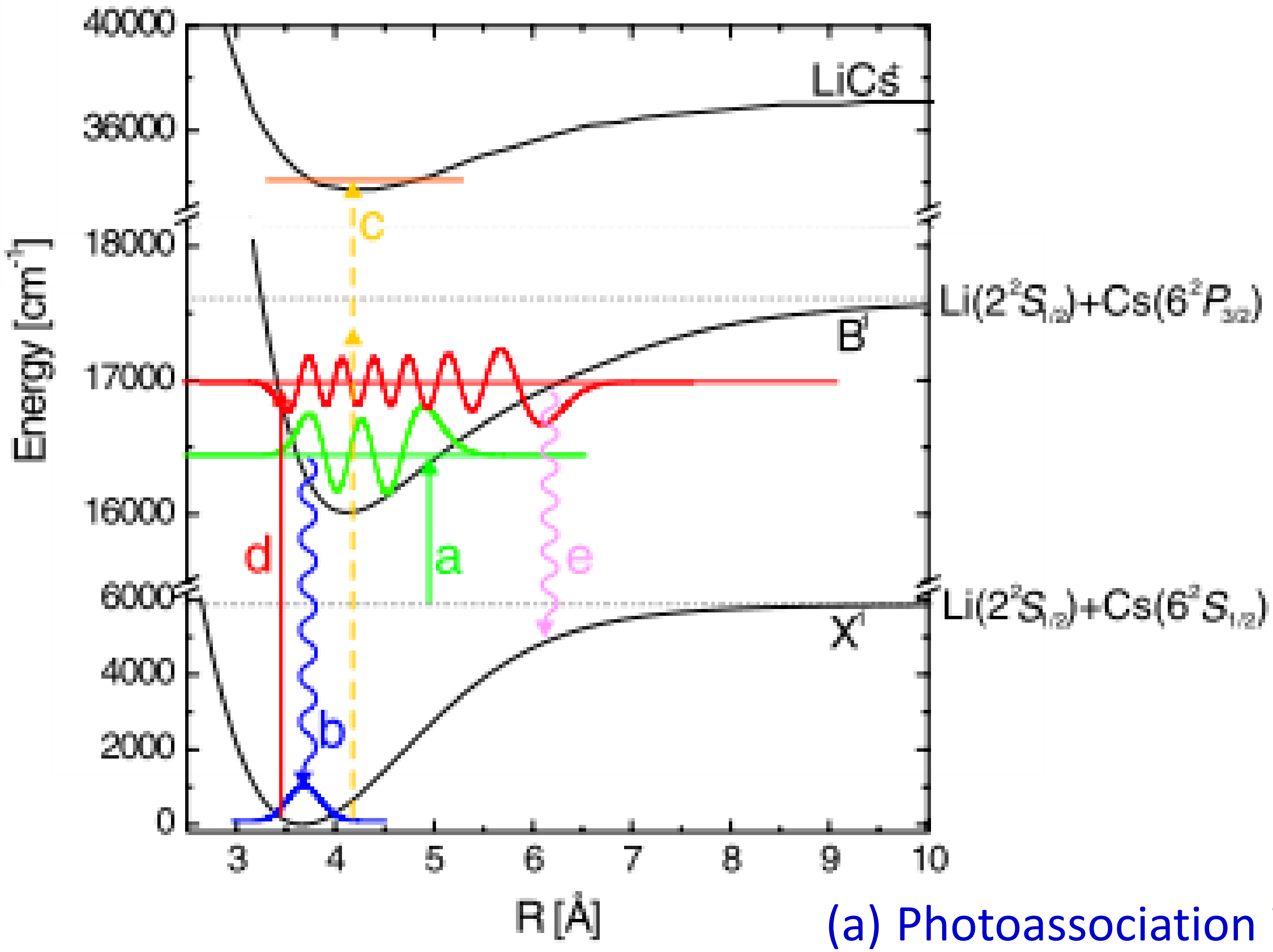


PRL **85**, 2292 (2000)



Rev. Mod. Phys. **78**, 483 (2006)

Example: production of ultracold LiCs in the ground state



(a) Photoassociation into v=4 (500mW, 946nm)
(b) Spontaneous decay into ground state
(c) Two-photon resonant ionization

5000 ground state molecules per second

PRL **101**, 103004 (2008)

Photoassociation - advantages and limitations

✓ Molecules are formed at ultracold temperatures

✓ Possible to reach the ground state (though difficult)

X Limited to constituents that can be laser-cooled

X High experimental complexity, particularly for heteronuclears

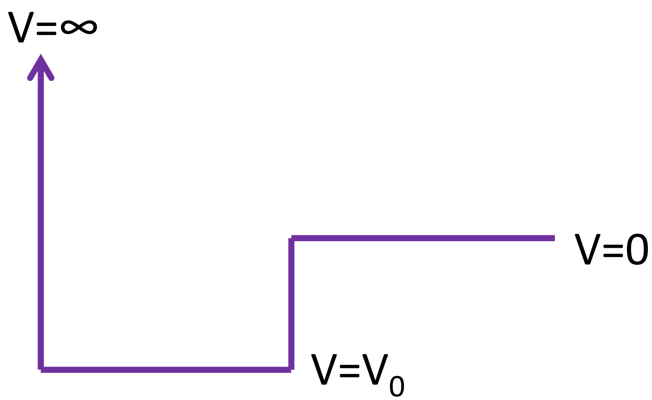
X Production rate is usually very slow

Feshbach resonance

Reminder about s-wave scattering

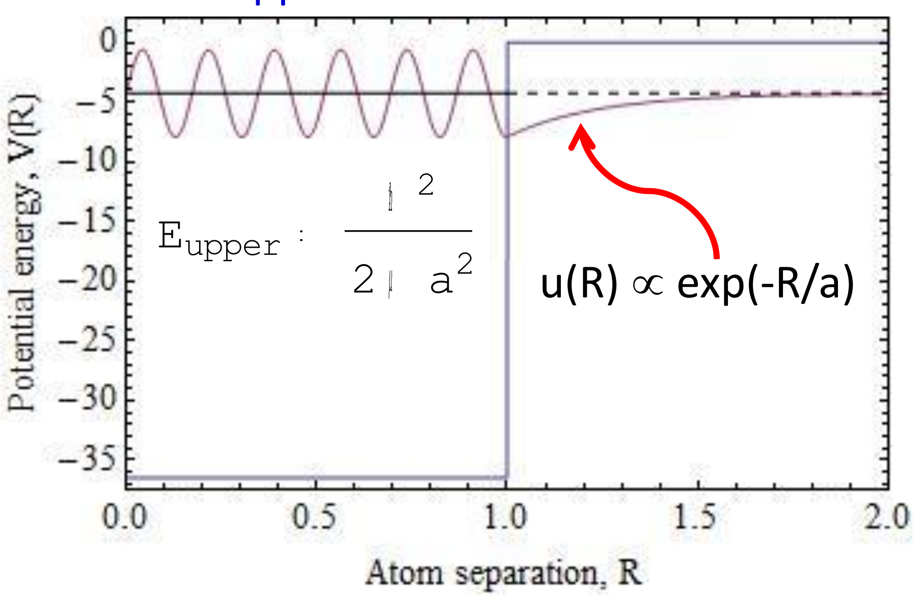
- At ultracold temperatures, scattering is described by the s-wave scattering length, a
- All other partial waves are suppressed by the angular momentum barrier

Toy example:

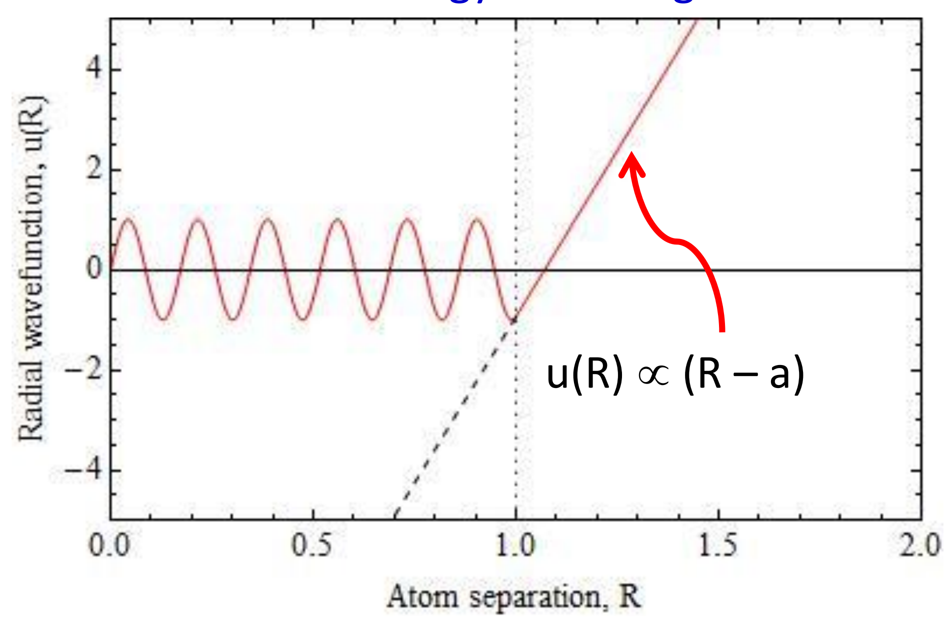


$$\boxed{\sigma = \frac{4\pi a^2}{1 + k^2 a^2}}$$

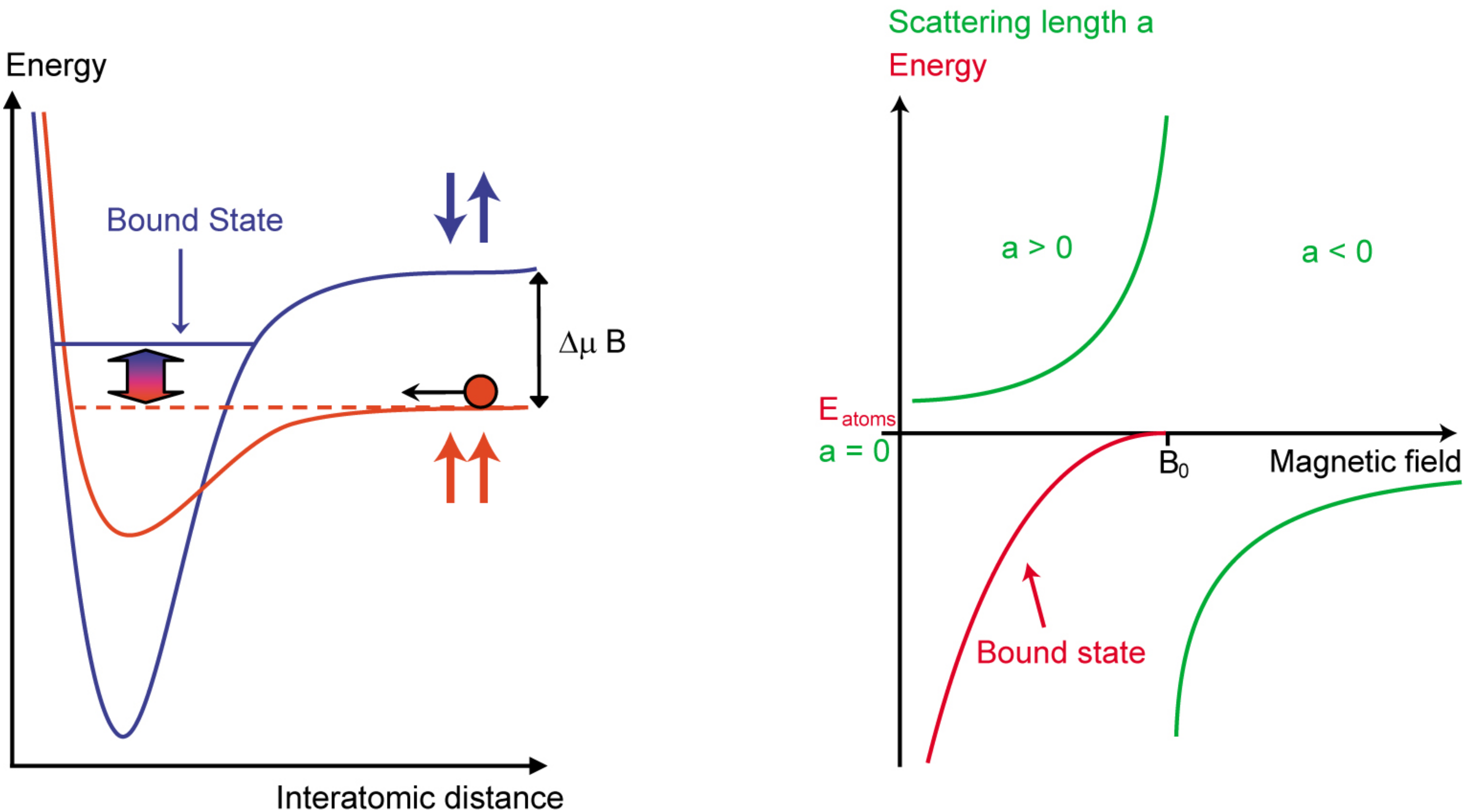
Uppermost bound state



Zero-energy scattering state

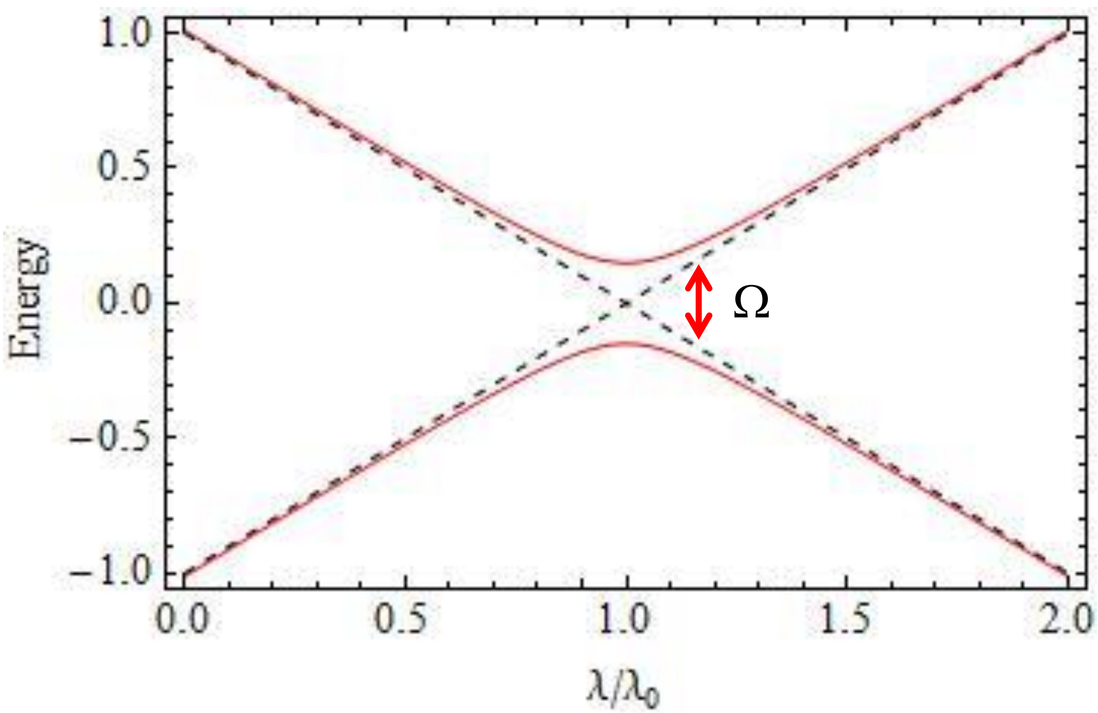


Feshbach resonance



Reminder about level crossings

$$\begin{pmatrix} \cdots & 0 & \cdots \\ \cdots & \cdots & 0 \end{pmatrix}$$



Atoms into molecules via a Feshbach resonance