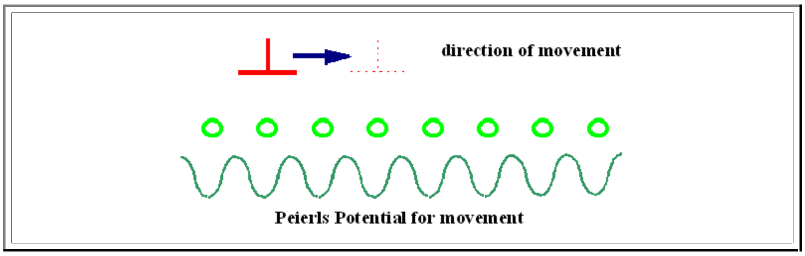
5.3 Movement and Generation of Dislocations

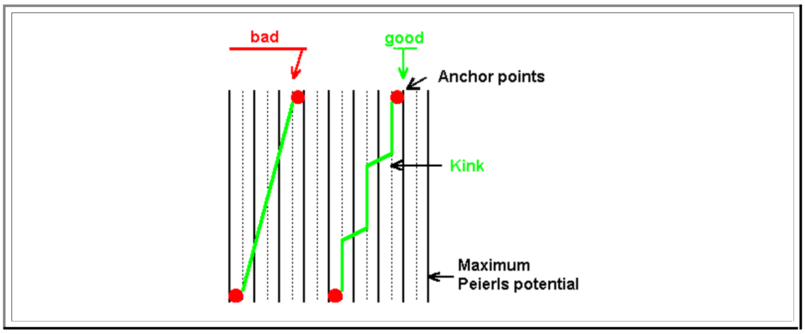
5.3.1 Kinks and Jogs

Kinks in Dislocations

- In most *crystals* and under most circumstances *there is no such thing as a straight dislocation*. Real dislocations contain **kinks** and **jogs** - sudden deviations from a straight line on atomic dimensions.
- These *defects within a defect* may strongly influence the mobility of dislocations and are thus of importance.
  - They owe their existence first of all to the fact that dislocations always "live" in a crystals - in a periodic arrangement of atoms. We have not used that fact so far, except in a rather abstract way for the very definition of dislocations with the Volterra cut. Now it is time to appreciate the effects of the crystal on the fine structure of dislocatons.
  - Kinks (and jogs) may be produced by several mechanisms, in particular they may be formed by the *movement* of the dislocation.
- First, let's look at ***kinks***. For that we first have to consider the concept of the **Peierls potential** of a dislocation.
  - Consider the movement of an edge dislocation as shown below. The green circles symbolize the last atom on the inserted half- plane of an edge dislocation. In local equilibrium its distance to the atoms to the left or right will be same for basic reasons of symmetry, cf. the perspective drawing of an edge dislocation.

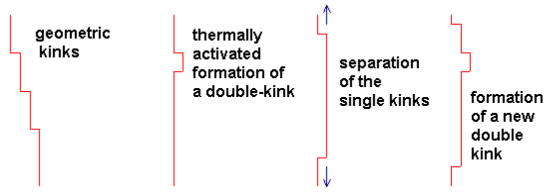


  - If the dislocation is to move, the last atom (and the ones above to some extent) has to press against the neighboring atom on one side and move away from the atom on the other side. That is clearly a situation with a higher energy which can be cast into a potential energy curve as shown in the illustration. At some point when both lattice plans are most affected, there is a maximum and a new minimum as soon as the dislocation has moved by one Burgers vector. The minima and maxima of this **Peierls potential** are along directions of high symmetry.
  - To overcome the maximum of the Peierls potential, the stress has to be larger than some intrinsic **critical shear stress** τ_{crit}.
- The Peierls potential defines special low-energy directions in which the dislocation prefers to lie. This is the *third* rule for directions that dislocations like to assume! (Try to remember the first and second rule, or use the links).
  - In other words, the inserted half-plane for the easy-to-imagine case of an edge dislocation should be clearly defined and should be in a *symmetric* position between its neighbour planes - exactly as we always have drawn it.
  - A dislocation that is almost, but not quite an edge dislocation, thus would prefer to be a pure edge dislocation over long distances and concentrate the "non-edginess" in small parts of its length as shown below. The same is true for screw dislocations, even so it is not quite as easy to contemplate.



  - The dislocation runs in the minima of the Peierls potential as long as possible and then crosses over briskly when it has to be. The transition from one Peierls minimum to the next one is called a *kink* as shown in the picture above.
- The kinks that come into existence in this way are called **geometric kinks**. But there is also a second kind, the **thermal equilibrium (double)-kink**, i.e. a crossing over to a neighboring Peierls valley followed by a "jump" back.
  - A kink, or better a double-kink, is simply a defect in an otherwise straight dislocation line, adding some energy *and* entropy. Since the **formation energy of a double kink** is not too large, they will be present in **thermal equilibrium** with concentrations following a standard Boltzmann distribution.

- To make that perfectly clear: While a dislocation by itself is never in thermal equilibrium, i.e. will never form spontaneously by thermal activation, this is not true for the defects it may contain. Double-kinks, seen as defects in a dislocation line, form and disappear spontaneously, if sufficient thermal energy is available; their number or density thus will follow a Boltzmann distribution.
- Once a thermal double-kink has been formed, the two single kinks may move apart; if the process is repeated, we have a *new mode of dislocation movement* for an otherwise perhaps immobile dislocation. This is shown below.



Kinks then are *steps of atomic dimension* in the dislocation line that are fully contained in the *glide plane* of the dislocation

- With this general definition, we can consider kinks in all dislocations, not just edge dislocations.

Screw dislocations have a Peierls potential, too, and thus they may contain kinks. The kink, per definition, is then a very short a piece of dislocation with *edge character*.

- This has far reaching consequences: A screw dislocation with a kink now either has a *specific glide plane* - the glide plane of the kink - or the kink is an anchor point for the screw dislocation.
- Kinks can do more: As indicated above, at not too low temperatures when the generation of thermal double kinks becomes possible, the applied stress may be below the critical shear stress needed to move the dislocation in toto (i.e. move it across the Peierls potential), but might be large enough to separate double kinks and thus promote dislocation movement and plastic deformation. We have one of several effects here that make crystals "softer" at high temperatures.

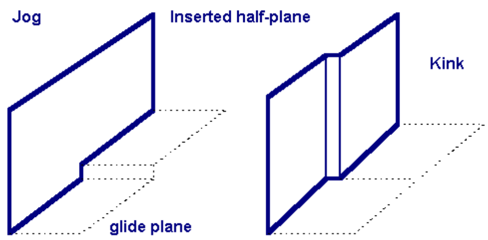
The best way to investigate kinks are **internal friction** experiments.

- An oscillating deformation is chosen, e.g. by vibrating a thin specimen driven by an electromagnetic field. The amplitude and thus the internal stress and strain are easily measured. As long as the stress is not too large, deformation proceeds by the generation and the movement of kinks. This is a fully reversible process and the response to an external stress thus is purely elastic even though a dislocation moved!
- However, in contrast to elasticity just coming from stretching the bonds between the atoms, the generation and movement of double kinks takes time and is strongly temperature dependent. Specific time constants are involved and a peculiar frequency dependence of the elastic response will be observed which contains information about the kinks.

Jogs in Dislocations

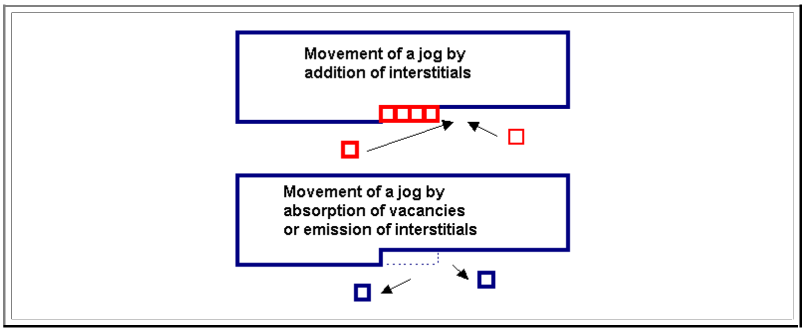
The term "**Jogs**" is sometimes considered to be the term for all "breaks" or steps in a dislocation line with atomic dimensions. Kinks then would be a subclass of jogs with the speciality of being in the glide plane.

- However, it is customary to use the term "jogs" for all *steps that are not contained in the glide plane*. Looking just at the inserted half-plane of an edge dislocation, jogs and kinks would look like this:



- But remember: Jogs and kinks can occur in any dislocation, not just edge dislocations - they are just not as easily drawn!

Jogs in edge dislocations are obviously prime places for the emission or absorption of point defects as is shown in the next illustration which looks at the inserted half-plane of an edge dislocation.



- The movement of jogs by emission or absorption of point defects means that the dislocation moves. This particular process of dislocation movement is called **climb of dislocations**. It is a movement that does *not* take place in the glide plane of the dislocation.

Generally speaking, we define:

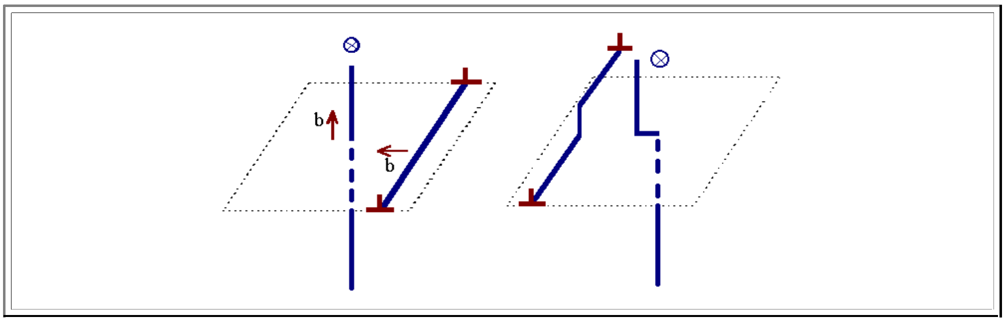
- **Conservative movement** of dislocations = movement in the glide plane = **glide** (for short) = movement without assistance of point defects.
- **Non conservative movement of dislocations** = movement not in the glide plane = **climb** (for short) = movement needing the assistance of point defects.

Generation of Kinks and Jogs

How do kinks and jogs come into existence? Three mechanisms can be identified.

- **1.** Thermally activated generation of double kinks as discussed above.
- **2.** Thermally *induced* generation of jogs by *absorption or emission of point defects*. This mechanism is thermally induced (and not "activated") because it responds to a super- or undersaturation of point defects. At large under- or supersaturations, the process becomes more likely. Here we have one of the source/sink processes needed for point defect equilibrium.
- **3.** Intersection of dislocations

The last process is new and needs some explanation. Lets look at the movement of an edge dislocation in the following geometry:



- The intersection of the edge dislocation with the screw dislocation produces one jog each per dislocation. (Consider the cut-and-move procedure and you will see why). It is clear that the same thing happens for the intersection of arbitrary mixed dislocations - a jog characterized by the Burgers vector of the dislocation that moved across will be generated.

This gives us a general relation and explains to some extent why plastic deformation is an extremely non-linear process:

- Movement of dislocations *generates* jogs.
- Jogs influence severely the *movement* of dislocations - so there is some *feedback* in the process of plastic deformation, and feedback of any kind is the hallmark of non-linear processes.

Considering jogs and kinks (together with knots), we start to consider *real* dislocations - and its getting complicated.

- And don't forget: All those great electron microscope pictures showing all kinds of dislocations, *never* show the jogs and kinks! They are simply too small. So even dislocation that look like perfect straight lines in a **TEM** picture, may be full of jogs and kinks.

There is one last property induced by these defects in a defect:

- Jogs, kinks and their combinations may produce "**debris**" left behind by a moving dislocation, because it is often "better" for dislocations to tear away from immobile parts like jogs, leaving behind a trail of point defects which in turn may agglomerate.

- If the jog is large extending over several lattice planes, a whole trail of small dislocation loops may form. The formation of a trail of vacancies in the wake of a jogged moving screw dislocation is illustrated in the link

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Some more text to come - but try the exercise anyway!

Exercise 5.3-1
Forces on a dislocation