

Figure 2. The hexagonal lattice packing in the plane.

we start with a brief review of the sphere packing and kissing number problems. Then we look at the remarkable kissing configurations in dimensions four, eight, and twenty-four. We give a sketch of Delbarte's method and how it was applied for the kissing number problem in dimensions eight and twenty-four. Then Mešin's ideas kick in, which leads us to look at some nonlinear optimization problems as they occur as subproblems in his approach. Finally, we sketch an elegant construction of the Leech lattice in dimension twenty-four, which starts from the graph of the icosahedron and uses only simple linear algebra. This is the lattice which Cohn and Kumar have now proved to be optimal

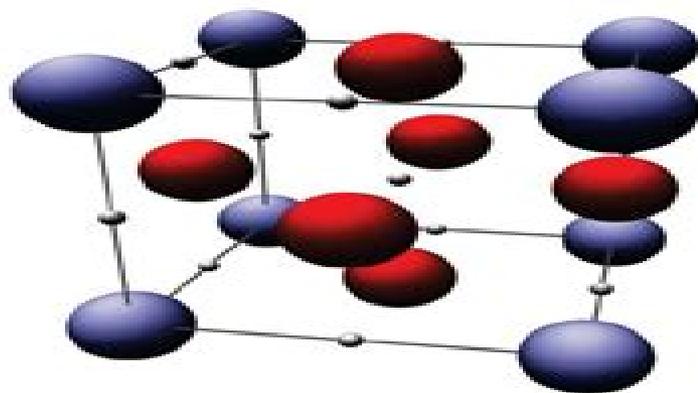
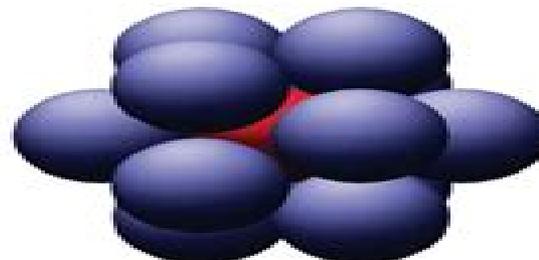


Figure 4. The fcc sphere packing.



Klaus Fink, 1989

Figure 3. The icosahedron configuration.

in dimension twenty-four by another extremely elegant and puzzling adaptation of Delbarte's method. A sketch for this will end our tour.

### Three Classical Problems

The "kissing number problem" is a basic geometric problem that got its name from billiards: two balls "kiss" if they touch. The kissing number problem asks how many blue balls can touch one given red ball at the same time if all the balls have the same size. If you arrange the balls on a pool table, it is easy to see that the answer is exactly six: six balls just perfectly surround a given ball.

The **sphere packing problem** is to determine the maximal density of a packing of balls (all of them of the same size) in Euclidean  $n$ -space.

One class of packings to consider are *lattice packings*, which are invariant under any translation that takes one ball of the packing to the other.

It is a simple exercise (recommended) to prove, for dimension two, that the "obvious" hexagonal packing of equal-sized disks (two-dimensional balls) in the plane—a lattice packing in which each disk touches  $\kappa(2) = 6$  others—is the optimal lattice packing and to compute its density.

It is not so easy to prove that the hexagonal packing is indeed an optimal sphere packing for dimension two. (Experts disagree whether the first proof for this, given by Thue 1892/1910, was indeed complete; if there was a gap, it was closed by Mähler and by Segre in 1940. See e.g. [14] for a proof.)

Thus the hexagonal planar lattice packing yields optimal solutions for the two-dimensional cases of the kissing number problem, the lattice packing problem, and the sphere packing problem. However, there are various indications that solutions of these three problems in higher dimensions are not so simple, they are not just given by "one perfect lattice packing", and things are much more complicated than in dimension two. This starts to show already in dimension three.

# Sphere Packings

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