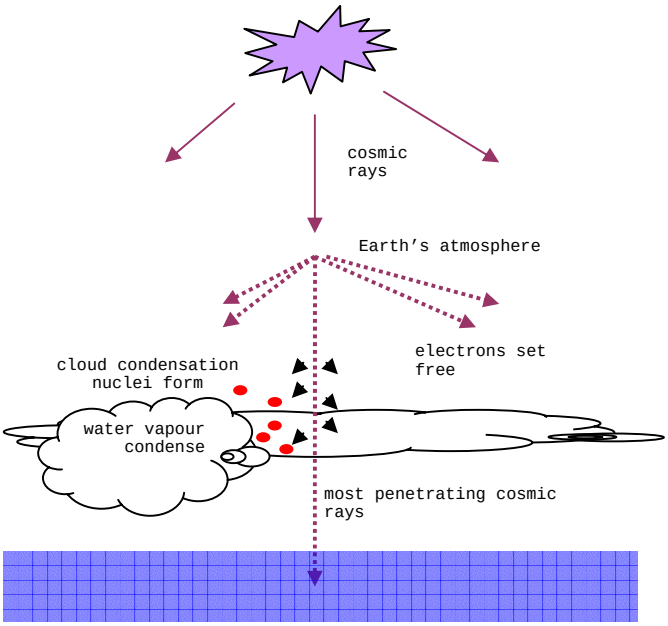
The SKY experiment in Copenhagen

To investigate the role of cosmic rays in cloud formation low in the Earth's atmosphere, SKY uses the natural muons (heavy electrons) that can penetrate even to the basement of the Danish National Space Center in Copenhagen. The hypothesis, verified by the experiment, is that electrons released in the air by the passing muons promote the formation of molecular clusters that are building blocks for cloud condensation nuclei.



Coming through the ceiling, the cosmic-ray muons pass through a reaction chamber in the form of a box with a volume of 7 cubic metres, made of Mylar plastic lined with Teflon. The reaction chamber contains air together with trace molecules like those found in unpolluted air in the natural environment. Inlets supply filtered air, sulphur dioxide and ozone, and the amount of water vapour is also under control. Ultraviolet lamps initiate a photochemical process creating sulphuric acid.

When sulphuric acid is added in concentrations below a critical value, vast numbers of aerosol particles appear in the reaction chamber. They are clusters of sulphuric acid and water molecules. Instruments measure the muon flux, electron density, and the numbers and sizes of the molecular clusters. Also recorded are temperature, pressure, relative humidity, and the concentrations of sulphur dioxide, ozone and radon – a natural radioactive gas.

Two electrodes mounted on opposite sides of the chamber allow a strong electric field to be applied, to sweep away the electrons. The expectation was that this would greatly reduce the count of molecular clusters and so confirm that electrons enhanced their production. When the team first tried the effect of the electric field, they were surprised to find that electrons with a life time of approximately 20 seconds made little difference to the cluster count.

The theoretical explanation, borne out by later trials, is that the electrons made the molecular clusters far more rapidly than anyone had imagined. Previous theories indicated that periods of more than 80 seconds would be needed. Clearing the SKY chamber of electrons took only 1 second, but by then the electrons had done their work. The role of the electrons is confirmed by the use of stronger electric fields, which sweep the electrons away more rapidly and greatly reduce the cluster count.

How nimble electrons clump molecules together

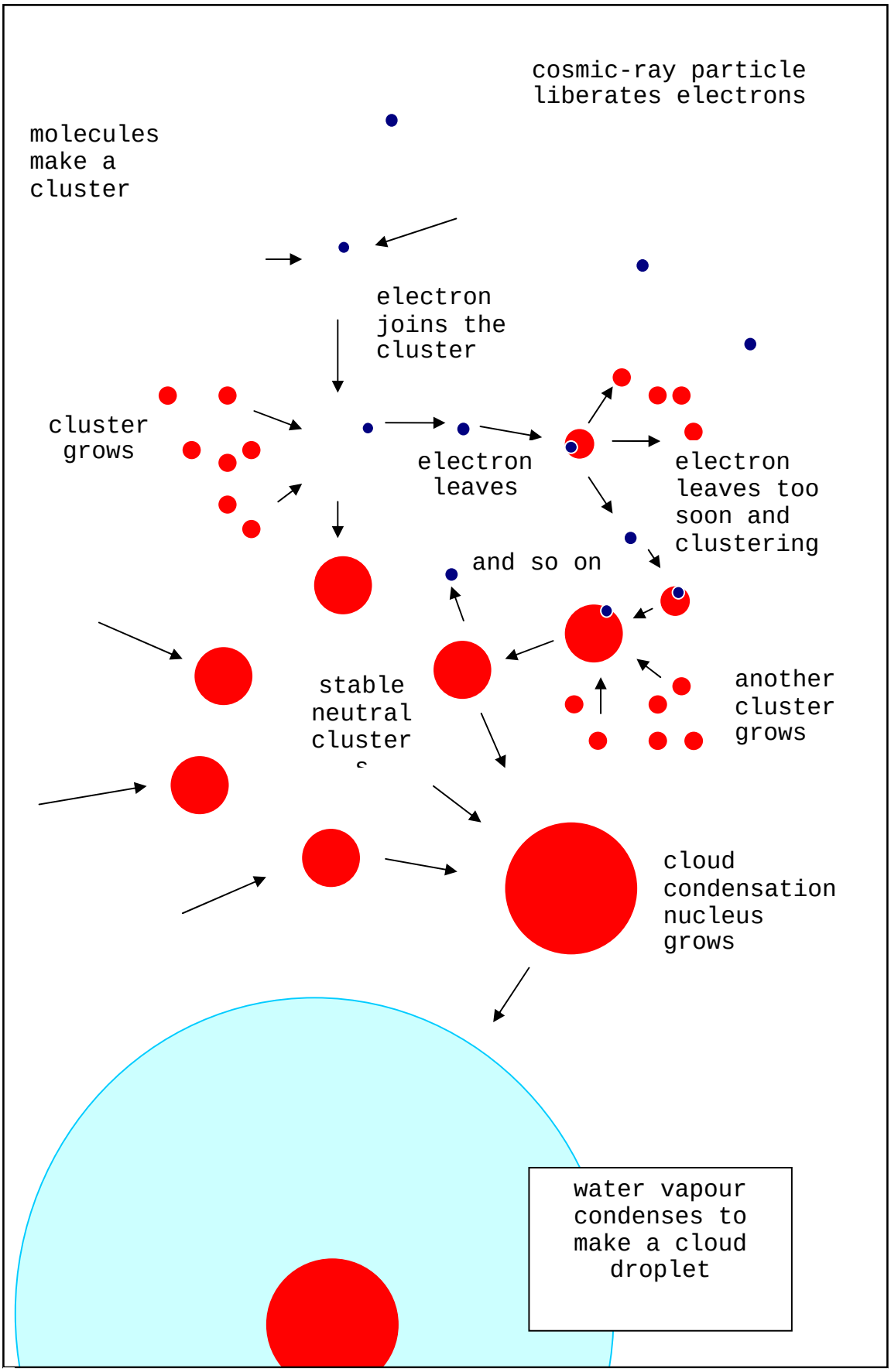
A kind of magic worked by electrons in the air over our heads helps to explain the formation of commonplace clouds, according to a new theory of Henrik Svensmark, who is Director of the Sun-Climate Center within the Danish National Space Center in Copenhagen. The theory describes mathematically the early growth of sulphuric acid droplets in the atmosphere. These are the building blocks for the cloud condensation nuclei on which water vapour condenses to make clouds.

Set loose by cosmic rays passing through the atmosphere, the electrons attach themselves to fragile clusters of sulphuric acid and water molecules. Their electric charges stabilize the clusters while more molecules join them. When the molecular clusters are big enough, the electrons can leave them in a stable state, and go off to encourage other clusters to grow.

In other words, the electrons act as catalysts, which promote chemical action while remaining unchanged themselves. A single electron can make many attempts to grow clusters, even though it will fail if it leaves too soon.

‘You can think of an electron as a teacher organizing several teams of children for a game,’ Svensmark says. ‘First one team, then another, and so on. In previous theories of cluster growth, each electron was supposed to remain with just one cluster – as if you needed a teacher for every team. The catalytic behaviour of the electrons is much more efficient.’

The theory explains in detail the surprisingly quick production of droplets seen in the SKY experiment by Svensmark and his team. It also accounts for the unexpected occurrence of very large numbers of ultra-fine droplets of sulphuric acid detected by research aircraft over the Pacific Ocean by atmospheric scientists.


cosmic-ray particle liberates electrons
molecules make a cluster
electron joins the cluster
cluster grows
electron leaves
electron leaves too soon and clustering
and so on
stable neutral cluster
another cluster grows
cloud condensation nucleus grows
water vapour condenses to make a cloud droplet