- Delft University of Technology, The Netherlands etc.

In some of these institutions, excellent collaborations exist with the Industries in the areas of optoelectronics and microelectronics[12]. Government support of these endeavours is usually quite generous in many developed countries. I would like to cite some examples of how other Governments are supporting their own research in nanostructures:

- The Ministry of International Trade & Industry in Japan has pledged $ 225 million over the next 10 years on developing nanotechnology; The Japanese Government funds promising researchers through the 'Exploratory Research for Advanced Technology (ERATO)' programme,
- The ESPRIT or RACE programmes of the European community.

Against this backdrop it would be worthwhile for our Government to support the research in microstructural sciences. It would be certainly wise to think in terms of an Institute devoted to experimental and theoretical studies of microstructures.

Finally, in order to start a new facility for microstructural studies, one needs the essential components like: (a) MBE machines to grow substrates, (b) characterization facilities, (c) lithography facilities, and (d) other experimental facilities, like dilution refrigerators, high field magnets, lasers, computers, etc. A rough estimate of the total cost for such a project would be $5–10 million.

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Low temperature facilities for condensed matter research

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The necessity for setting up low temperature facilities, which will be accessible to scientists working in the area of condensed matter physics in universities, is emphasized in this paper. A minimum list of plants and equipment and an estimate of the cost of establishing such facilities are presented. Some suggestions for effective operation of such facilities are also made.

In the past twenty-five years the volume of work in condensed matter physics has increased enormously worldwide. New and interesting discoveries have been made in this field with surprising regularity. In India also the volume of research in condensed matter physics has been growing. While the quantity of work in condensed matter has grown, one cannot say the same of the quality, especially of experimental research. It is true that there are a few institutions in India in which good experimental research is being conducted. But they are a few cases in a barren desert. I am convinced that experimental research will flower in the long run only if the majority of workers in the field, who are in the universities, are provided certain minimum facilities for meaningful work. One such essential facility is for research in low temperature physics.

Importance of low temperatures in condensed matter research

To an audience of condensed matter scientists it is not necessary for me to dwell on the importance of low temperatures in condensed matter research. At low temperatures many excitations in condensed matter die down and one can study the material properties without interference from these excitations. Apart from this there are several new quantum phenomena which occur 'only at low temperatures'. I need only mention superfluidity both in ^4He and ^3He, superconductivity, effects arising from quantum confinement in low dimensional systems and in mesoscopic structures, etc.

Man's constant quest to reach the absolute zero has met with success and rich dividends. One is able to produce now temperatures down to 20 mK routinely in the laboratory through the use of the dilution refrigerator. Temperatures down to a few micro-degrees Kelvin for the lattice temperature and a few nano-degrees Kelvin for the spin temperature have been achieved in the single shot process of nuclear adiabatic demagnetization. However, expertise in this ultra-low temperature technique is confined to a few laboratories in the world. Pobell puts it admirably in his book *Matter and Methods at Low Temperature*: 'The very wide range of temperature accessible to experiments has made temperature probably the most important among the parameters, which can be varied in the laboratory in order to change the properties of matter, to obtain a better understanding of its behaviour, and to make practical use of it.'

Low temperature facilities in India

While in the developed countries measurements down to 4.2 K are being routinely carried out in many laboratories, the scenario in India is different. The majority of workers in condensed matter physics, who are in the universities, have no access to research at low temperatures. After the advent of high temperature superconductors, a few of them were able to acquire closed circuit refrigerators reaching down to 15 K. However I do not know how many of these are in working condition now.

Research down to 4.2 K is confined to the DAE institutions, the IISc, some of the IITs and the NPL. These institutions, approximately fourteen in number, have running helium liquifiers. There are three institutions with ^3He cryostats with which one may reach temperatures down to 0.3 K and one institution with a dilution refrigerator with which one may reach temperatures down to about 30 mK. Compared to the number of scientists working on condensed matter physics in this country the available low temperature facilities are woefully short. There is a need to establish a few centres where low temperature facilities will be available and which can be used by any worker from any university or other institution.

Establishment of minimal low temperature facilities

I believe the following will be the minimal facilities required:

- Liquid nitrogen plant (20 l/h) with a 2000 l storage tank; the plant should be modular type so that it provides for future expansion by adding modules.
- Liquid helium plant (10 l/h) with a 250 l storage vessel; the production capacity should be capable of being augmented if required by the addition of compressors and a bigger storage vessel. There should be a recovery compressor with adequate capacity.
- A roots pumping system to reduce the pressure on liquid helium to achieve temperatures down to 1.5 K.
- A dilution refrigerator providing 5 uW of refrigeration at 20 mK. This should have its own gas handling system.
- A 5 cm bore Nb-Ti superconducting magnet with power supply and a Nb_3Sn insert to reach fields of 12 to 13 T.
- A portable helium mass spectrometer leak detector.
- Cryostats of different types for measurements down to 1.5 K and inserts for dilution refrigerator, transfer tubes, etc. to be indigenously designed and fabricated.
- Temperature controllers, constant current sources, nano- and pico-voltmeters, Hall probes, etc. for a variety of purposes.
- Chilled water units, air conditioners, voltage stabilizers, vacuum hardware.
- Minimum workshop facilities.
- Building for the above.
- The running costs should include.
- Spares for the nitrogen and helium liquifiers.
- Helium gas (initially 1000 Nm^3. Replacement gas approximately 500 Nm^3 per year depending on use).
- Thin walled SS tubes of different diameters.
- Sensors for temperature measurements in different ranges
- Low temperature adhesives, varnish, feed-throughs, etc.
- Salary of well-trained low temperature physicists and engineers, plant operators, and vacuum technicians.
- TA/DA for users.

The total initial cost for such a facility will come to about Rs 50 to 70 millions and the running costs per year to about Rs 10 to 15 million.

Organization

It is necessary to set up at least two such centres to start with, one in the north and one in the south. It is not necessary to set up all the facilities *de novo*. If there are well run laboratories with demonstrated experience for continued operation and maintenance of existing liquifiers, the facilities in these centres can be augmented. *However a condition must be imposed that such a centre will serve the needs of all users and not only of those in the institute in which the laboratory is located.*

If such a centre is established in a big institution, it should have complete autonomy with full powers to manage its finances and to have its own speedy purchase procedures.

It is necessary to keep the strength of staff to a minimum. A small institution can be more efficient and problem-free than a big one.

Method of operation

The administrative head of the centre must keep in mind constantly the purpose for which the centre has been set up, namely to help the users in performing experiments at low temperatures to develop meaningful expertise and obtain results. He must prepare a detailed plan on how the institution will come up, what facilities it will offer the user and in what time frame these facilities will be made available. This must be presented before a gathering of scientists and scientific administrators to get their suggestions. Once the plan is approved and money becomes available, he and his team must put the plan into execution effectively. Every scientist/engineer/technician must be assigned specific work which should be completed in the allotted time. *The personnel must be made to realize that costly equipment should not be allowed to remain idle for long periods and down-time of an equipment must be minimal.* In order to motivate the personnel to keep the equipment in good trim, the scientist/engineer must have his own R & D programme to which he can devote 30% of the time. The rest of the time must be spent in helping the user. The activities of the centre must be monitored by an Advisory committee which will also assess the contributions of scientists and engineers every year, Personnel should be appointed only if it is felt that they will have enough work to keep them busy. Training programmes should be mounted to train users from different parts of the country in cryogenic techniques. Scientific and engineering personnel must be involved in developing cryostats in co-operation with the user. Since the making of cryostats involves advanced fabrication techniques, companies must be identified whose staff will work in collaboration with the staff of the centre to gain experience in fabrication. It will be necessary to build experience in the industry if we want to avoid complete dependence on imports.

Once a large number of users develops, the allocation of time must be monitored by a users' committee.

If such a centre is to succeed certain attitudinal changes are required:

- The administrative decisions must be made by technical persons and the duty of the bureaucratic staff must be to implement the decisions effectively. The number of bureaucrats must be kept to a minimum.
- Purchase procedures must be fast. After the technical committee takes a decision on the purchase of an item the processing of the order should be completed within a couple of days.
- Any breakdown of equipment must be attended to immediately and faults rectified with minimum delay.
- The scientific and technical staff must be willing to spare their time and effort in helping the users. This must be one of the important criteria on which future advancements of scientists, technicians should be based.
- An engineer who maintains a plant efficiently or a technician who sets up an experiment to work flawlessly is as valuable to the organization as a scientist who publishes a paper. So such people must be given adequate recognition of their work in terms of status, pay and promotional opportunities.
- The interaction with theoreticians in the country must be strong.