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DHVĀNTAPRAMĀPAKA YANTRA OF MAHARṢI BHARADVĀJA
(Spectrometer/Monochromator)

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The paper deals with the description of *Dhvāntaparmāpaka Yantra*, a novel spectrometer, described in *'Aṃśu Bodhinī'* of *Maharṣi Bharadvāja* (with a commentary by *Bodhāṇanda*). The instrument is useful in studying the spectra of optical region comprised of ultra-violet, visible and infrared regions with a facility to choose any one option at a time.

The instrument has been presented diagrammatically. Since the instrument uses a conical prism in place of conventional prisms or their combinations, the necessary scientific mathematical calculations have been carried out to understand the concept and working of the instrument. The calculations indicate linear dependence of the wave numbers ($\bar{\upsilon}$) on the square root of the difference of radii of the spectral ring in reference with that of the limiting value $\bar{\upsilon} = 0$. Thus the instrument can measure the wave number directly with the help of a properly graduated linear scale, an entirely new technique not prevalent in modern times.

INTRODUCTION

From the library of Oriental Institute, Vadodara (Baroda) a manuscript of *Maharṣi Bharadvāja* titled *'Aṃśu-bodhinī'* (with a commentary of *Bodhānanda*) was received. In the introductory passages, it is said that in the original text of *Bharadvāja*, the aphorisms of *'Aṃśu-bodhinī'* are divided into twelve chapters having one thousand sections. In order to make it understandable, *Bodhānanda* wrote a commentary on it. Actually the available manuscript is the first chapter of the work, having a commentary over the first fifty aphorisms of *Maharṣi Bharadvāja*. The title of this chapter is *'Sṛṣṭyādhikāraḥ* i.e. the Evolution of the Universe. As one goes through the literature, he finds that this commentary appears describing the details of evolution of universe right from 'Big-Bang' to the evolution of Sun of our Solar System. In this course of explanation they have described *'Dhvāntapramāpaka-yantram'* or *'Tamapramāpaka-yantram'*. From the description of the instrument it is easy to infer that it is probably one device out of the five devices which were used to measure the spectra of the three optical regions, namely infrared (i r) visible (v) and ultraviolet (u v) region, as the text describes an instrument which is capable to divide *'dhvānta'* or *tama* while in general sense into the three components, viz, *'andhaṃtama'*, *'gūḍhaṃ-tama'* and *'tama'*. There is a clear but short description regarding how the separation of the

The instrument has been fabricated by the author himself at the Sah Industrial Research Institute, it is hoped that this publication will inspire some other competent experts to fabricate and validate such an instrument – Editor

components having sun (light) is done by the use of this instrument. Here it is vivid to the reader that the *'dhvānta'* of *'gharma'* property are heat rays or more specifically ir rays. The *'dhvānta'* component having the property of *prabhā* is nothing but the illuminating rays or visible rays. Thus, *dhvānta* component of *'chāyā'* property must be the u v-rays as the bodies illuminated by u v-rays only cannot be seen by naked eyes. Moreover, *dhvānta* term does not appear to mean the absence of light but as the term denotes radiations in general. Thus the three terms *'andhaṃtama'*, *'gūḍhamtaṃa'* and *'tama'* appear to indicate ultraviolet, visible and infrared radiations respectively. In this commentary of *Aṃśubodhinī* it is also claimed that these are also known as *'tama'*, *'sattva'* and *'raja'* respectively in the Indian philosophical texts. The colours of these properties are *kṛṣṇa* (blue or violet), *śukla* (white) and *rakta* (red) which hints as well as has an obvious consistency of the association of these colours with the modern scientific terms. Therefore, *Dhavāntapramāpaka-yantra* described here is possibly one of the ancient spectrometers. The description of the apparatus as described in the text of *Aṃśu bodhinī* from page 69 to 77 is given below :

The apparatus has 13 ancillary components :

।।शारिकानाथः।।

ध्वान्तप्रमापकं यन्त्रं नवोत्तरशतात्मकम्। द्वात्रिंशदंगसंयुक्तं तमोभेदप्रदर्शकम्।।
उक्तं हि यन्त्रसर्वस्वे भरद्वाजेन धीमता। तस्य त्रयोदशांगेन प्रमातुं तमसो भवेत्।।
तस्मादत्र समासेन तदंगं प्रविविच्यते।

Prose form:

नवोत्तरशतात्मकं द्वात्रिंशद् अंगसंयुक्तं तमोभेदप्रदर्शकं ध्वान्तप्रमापकं यंत्रं यंत्रसर्वस्वे धीमता भरद्वाजेन उक्तम्। तस्य त्रयोदशांगेन तमसः प्रमातुं भवेत्। तस्माद् (कारणात्) अत्र (प्रकृत प्रसंगे) समासेन तद् (तस्य यंत्रस्य) अङ्गं प्रविविच्यते।

In the work *'Yantra-sarvasva'* the learned *(Maharṣi) Bharadvāja* described *'Dhvāntapramāpaka – yantra'* (Radiation measuring apparatus or spectrometer monochromator) as 109th instrument comprised of 32 ancillary components, which is capable to analyse the radiation in general. Further, according to *Śārikānātha,* as out of 32 components only 13 components are sufficient to analyse *'Tama'* (ultraviolet, u v) for the present moment only these (13) components are described here (Fig. 1).

Ancillary component 1 and 2:

यंत्रस्थद्वादशांगस्य पूर्वभागे स्थिते क्रमात्।
चतुरश्रे यथाशास्त्रं वर्तुलं भारवर्जितम्। वितस्तिदशकायामं सुदृढं च सुसूक्ष्मकम्।
छायापकर्षणादर्शषडुत्तरशतात्मकम्। शास्त्रोक्तविधिना सम्यक्स्थापयेत्सुदृढं ततः।।

Prose form:

यंत्रस्थद्वादशांगस्य पूर्वभागे स्थिते क्रमात् चतुरश्रे यथाशास्त्रं भारवर्जित वर्तुलं वितस्तिदशकायामं सुदृढं सुसूक्ष्मकं षडुत्तरशतात्मकं छायापकर्षणादर्शं, शास्त्रोक्तविधिना सम्यक् सुदृढं स्थापयेत्। ततः –

In the first place, over a square base *(caturaśre)* of requisite size and rigidity, as technically required (i.e. of 120x120 *aṅgula*), being the first component, a circular, thin and uv transparent glass plate of serial number 106 *(Chāyāpakarṣaṇādarśa-cakra)* of 120 *aṅgula* diameter, out of the rest 12 ancillary components of the instrument (i.e. as the 2nd component) is fixed rigidly by technical methods.

Ancillary component 3:

चतुरंगुलमायामं षड्वितस्त्युन्नतं तथा। इतरांगैस्समाहृतविद्युत्तंत्र्यादिभिर्युतम्।
स्वमध्यादन्तपर्यन्तं वितस्त्येकांतरं यथा। रंध्रत्रयेण संयुक्तं शिलाकाचविनिर्मितम्।
मेरुस्तंभाख्यशंकुं तन्मध्ये संस्थापयेद्दृढम्।

Prose form:

(ततः) चतुरंगुलम्। आयामं षड्वितस्त्युन्नतम् इतरांगैः समाहृतविद्युत्तंत्र्यादिभिः युतम्, स्वमध्याद् अन्तपर्यन्तं वितस्त्येकान्तरं यथा (भवेत् तथा) रंध्रत्रयेण संयुक्तं शिलाकाचविनिर्मितं मेरुस्तंभाख्यशंकुं तन्मध्ये दृढं संस्थापयेत्।

Further, a rod (*śaṅku* as third component) called central pillar *(merustambha)* of 4 *aṅgula* diameter and 72 *aṅgula* height (6 *vitasti*) made of stony glass *(śilākāca)*, having three holes right from the centre to the end 12 *aṅgula (vitasti)* apart and also having electrical wirings brought from the other components, is rigidly fixed at the centre of the base

Ancillary Component 4:

पश्चात्तृतीयरंध्रस्य पार्श्वयोरुभयोरपि।
दृढं दशांगुलायामं क्रमात्षष्ट्यंगुलोन्नतम्। शास्त्रोक्तविधिना दंडमेकं संधारयेद्दृढम्।।
तथा द्वितीयरंध्रस्य पार्श्वयोरुभयोरपि। क्रमादष्टागुलायामं पंचाशदंगुलोन्नतम्।
दण्डं संधारयेत्तद्वत्सुदृढं काचनिर्मितम्। एवं प्रथमरंध्रस्य पार्श्वयोरुभयोरपि।
चत्वारिंशत्यंगुलोन्नतमायामे षडंगुलम्। दंडं संयोजयेत्पूर्ववद्दृढं काचनीर्मितम्।
दंडप्रमाणमुभयोस्समानमपि पार्श्वयोः। किंचिदूर्ध्वं भवेद् दक्षे वामेऽधः स्यात्स्थितिर्यथा।
तथा संधारयेत्तेषु दंडानि त्रीणि यथाक्रमम्। पूर्वोक्ततंत्रिभिर्युक्तचक्रकीलान्यथाविधि।
दंडानां मूलदेशे संधारयेत्पार्श्वयोःक्रमात्।

Prose form:

पश्चात् तृतीयरंध्रस्य उभयोः पार्श्वयोः अपि दशांगुलम् आयामं क्रमात् षष्ट्यंगुलोन्नतम् एकं दण्डं शास्त्रोक्तविधिना दृढं संधारयेत्।

द्वितीयरंध्रस्य उभयोः पार्श्वयोः क्रमाद् अष्टांगुलं आयामं पंचाशद् अंगुलोन्नतं तद्वत् (पूर्ववत्) सुदृढं काचनिर्मितं दण्डं संधारयेत्। एवं प्रथमरंध्रस्य उभयोः पार्श्वयोः चत्वारिंशत् अंगुलोन्नतम् आयामे षडंगुलं काचनिर्मितं दण्डं दृढं पूर्ववद् संयोजयेत्। उभयोः पार्श्वयोः दण्डप्रमाणं समानम् अपि दक्षे किंचित् ऊर्ध्वम् (तथा) वामे अधस्तात्स्थितिः यथा भवेत् तथा तेषु त्रीणि दंडानि यथाक्रमं संधारयेत्। पार्श्वयोः क्रमात् पूर्वोक्ततंत्रिभिःयुक्तचक्रकीलान् दण्डानां मूलदेशे यथाविधि संधारयेत्।

Afterwards at both the sides of the third hole 10 *aṅgula* apart from *'Divākarādarśa-cakra* (the description is given in the following passages) rods of 60 *aṅgula* heights are to be fixed and then at both the sides of the second hole.

Ancillary component 5:

8 *aṅgula* apart from *'Bhānuphalaka'* (the description is given in the following passages) rods of 50 *aṅgulas* in heights made of glass are to be rigidly fixed.

Ancillary component 6:

Similarly at both sides of the first hole, glass rods of 40 *aṅgula* heights at 6 *aṅgula* apart from *Prabhāmukhādarśa-cakra* (the description is given later) are to be fixed rigidly as it was done in the previous cases.

Though the heights of the rods of both the sides of the pole are nearly equal, yet in general the position of the rod of right side is slightly higher than the corresponding hole while that of the left side is slightly lower than the same hole. This is the case with all the three pairs. According to the method described earlier, on both the sides of central pillar (*merustambha*), pulley axle systems with ropes are fixed near the bases of the rods.

Further remarks on ancillary 2:

पश्चाच्छायापकर्षणदर्पणे शास्त्रतःक्रमात्।
शंकुस्थानाद्दक्षवामपार्श्वयोरुभयोरपि। त्रिंशत्त्रिंशल्लिखेद्रेखा दर्पणान्तावधि क्रमात्।
अहःप्रमाणघटिकान्दक्षरेखास्तयोःक्रमात्। रात्रिप्रमाणघटिकान्वामरेखास्तथैव हि।।
प्रदर्शयन्ति संख्यातःतथा विघटिकान्क्रमात्। तेषु दर्शयितुं रेखाश्चतुष्षष्ठिर्विलेखयेत्।।
सर्वत्र रेखान्त्यभागे बिन्दूनंकसमन्वितान्। स्फुटं विलेखयेत्तद्वत्तदन्तस्सूक्ष्मतस्तथा।।

Prose form:

पश्चात् छायापकर्षणदर्पणे शंकुस्थानात् शास्त्रतः क्रमात् दक्षवामोभयोः पार्श्वयोः दर्पणान्तावधि क्रमात् त्रिंशत् रेखाः लिखेत्। तयोः क्रमात् दक्ष (दक्षे) अहःप्रमाणघटिकान् रेखाः तथा वाम (वामे) रात्रिप्रमाणघटिकान् रेखाः संख्यातः प्रदर्शयन्ति।

तेषु विघटिकान् दर्शयितुं क्रमात् चतुष्षष्टिरेखाः विलेखयेत्। सर्वत्र रेखान् अन्त्यभागे अंकसमन्वितान् बिन्दून् स्फुटं विलेखयेत्, तद्वत् तत् अन्तः सूक्ष्मतः (विलेखयेत्)।

Later on, both the sides of central pillar (*śaṅku*), i.e. on the right and left sides of *chāyāpakarṣaṇādarśa-cakra* be marked with lines denoting thirty angular divisions (where every aṅgula division equals 6). These are equivalent to *'ghaṭī'* divisions marked in digits of the day and the night in the right and left sides (of *cakra*) respectively.

Ancillary component 7:

पंचाशदंगुलायामं विस्तीर्णं तावदेव हि। त्रिंशद्रेखांचितं पश्चादनुलोमविलोमतः।।
स्वरूपे भानुवद्भासमानं स्वकिरणैस्स्वतः। प्रभाकरमणिं शुद्धमष्टाशीत्यात्मकं लघु।।
धारयन्तं मध्यभागे आतपोष्णादिभिर्युतम्। प्रभाकरादर्शचक्रं सूर्यप्रतिनिधिं दृढम्।।
मेरोस्तृतीयरंध्रस्य दक्षदण्डान्त्यकेन्द्रके। त्रिचक्रकीलकैस्सम्यक्स्थापयेद्भ्राम्यते यथा।

Prose form:

पञ्चाशदङ्गुलायामं तावत् एव हि विस्तीर्णं पश्चात् अनुलोम–विलोमतः त्रिंशद्रेखांचितं स्वकिरणैः स्वतः स्वरूपे भानुवद् भासमानम् अष्टाशीत्यात्मकं शुद्धं लघुप्रभाकरमणिं धारयन्तं मध्यभागे आतपोष्णादिभिःयुतं सूर्यप्रतिनिधिं प्रभाकरादर्शचक्रं मेरोः तृतीयरंध्रस्य दक्षदण्डान्त्यकेन्द्रके दृढं यथाभ्राम्येत (तथा) त्रिचक्रकीलकैः सम्यक् स्थापयेत्।

Then probably a collimating element (a small *'prabhākara-maṇi'*, of serial number 80 and bright as sun) is fixed over a graduated circular plate by thirty-thirty lines on either sides (clockwise and anti-clockwise) of diameter 50 aṅgula *(Prabhākarādarśa-cakra)* which is placed centrally just above the third hole so that it may be revolved with the aid of three pulley-axle system fixed at the right side of the pole.

Ancillary component 8:

पश्चाद्दिवाकरादर्शवद्रेखाबिन्दुभिर्युतम्। सुधाद्रवशशोषादिद्रावकैश्च सुसंस्कृतम्।।
एतत्संस्कारतश्श्वेताभ्रवद्भास्वरमद्भुतम्। आकारेणांशुभिश्चैव चन्द्रमण्डलवत्स्थितम्।।
भ्राजमानं सप्तपंचाशदुत्तरशतात्मकम्। किरणग्राहकमणिं दधानं मध्यकेन्द्रके।।

पंचचत्वारिंशदंगुलायामं वर्तुलं तथा। षोडशोत्तरद्विशतसंख्याकं सुदृढं लघु।।
निशाकरादर्शचक्रं चन्द्रप्रतिनिधिं क्रमात्। पूर्ववत्तृतीयरंध्रं वामदण्डान्त्यकेन्द्रके।।
संधारयेत्कीलकाद्यैस्स्वतस्संचाल्यतेयथा।

Prose form:

पश्चात् दिवाकरादर्शवत् रेखाबिन्दुभिःयुतं सुधाद्रवशशोषादिद्रावकैः सुसंस्कृतं (कार्यम्)। एतत् संस्कारतः श्वेताभ्रवद्भास्वरम् आकारेण अंशुभिः च एव चन्द्रमंडलवत् स्थितं भ्राजमानं सप्तपंचाशत् – उत्तर – शतात्मकं किरणग्राहकमणिं मध्यकेन्द्रके दधानं, पंचचत्वारिंशत् अगुलायामं वर्त्तुलं तथा षोडशोत्तर–द्विशतसंख्याकं सुदृढं चन्द्रप्रतिनिधिं लघुनिशाकरादर्शचक्रं क्रमात् तृतीयरंध्रं वामे दण्डान्त्यकेन्द्रके कीलकाद्यैः संधारयेत्, यथा स्वतः संचाल्यते।

Again a circular glass plate known as *Niśākarādarśa-cakra* of serial number 206 of diameter 45 *aṅgula* along with a conical prism as dispersing element *(kiraṇagrāhaka-maṇi)* is placed centrally above the third hole of the central pillar *(merustambha)* and is connected to the arrangement of pulley axis systems fixed on the rod of the left part. Probably, by the action of lime water (*sudhādrava,* $Ca(OH)_2$) and acids of bones of hares or other small animals (H_3PO_4, *śaśoṣādi-drāvaka*) a white precipitate of calcium phosphate is deposited over the circular plate which gives moonlike look to the plate.

Ancillary component 9:

श्वेतदूर्वाकमलपुष्पक्षाराष्टकमतःपरम्।।
ताम्रषोडशके चूळीताम्रषोडशकं तथा। द्वादशस्वर्णलोहेषु हिरण्याष्टकमेव च।।
गोदन्तीतालषट्कं च सूतपन्यकमेव च। सूर्यकान्तशिलाषट्कमेतान्संयोज्य भागशः।।
क्रमान्माधिममूषायां संपूर्याथ यथाविधि। कूर्मव्यासटिकामध्ये स्थाप्यंगालादिभिःक्रमात्।।
द्वात्रिंशदुत्तरचतुश्शतकक्ष्योष्णमानतः। गालयित्वा यंत्रमुखे तद्रसं पूरयेत्क्रमात्।।
उष्णापकर्षकं नाम लोहं स्यात्कृतकं ततः। तेन प्रकल्पितं भानुफलकं मधुवर्णकम्।।
निशाकरादर्शचक्रादपि न्यूनं षडंगुलम्। बिन्दुरेखांकनैर्युक्तं अवटद्वयसंयुतम्।।
प्रथमावटमध्यस्थपारदे सन्निवेशितम्। चतुष्षष्ट्युत्तरशत संख्याकं भारवर्जितम्।।
घर्मापहारकमणिं बिन्दुरेखांकनैर्युतम्। दधानं सुदृढं सूक्ष्ममेरो रूर्ध्वं यथाविधि।।
क्रमाद्द्वितीयरंधस्थदक्षदण्डान्त्यकेन्द्रके। त्रिचक्रकीलकैस्सम्यक्स्थापयेद्भ्राम्यते यथा।।
मणिसंयोगतःपश्चादवटे निमिषार्धतः। मणिमन्तरतःकृत्वा घनत्वं याति सूतकम्।।
एतन्मणिस्सूर्यकिरणप्रकाशोष्णं स्वशक्तितः। समाकर्षति वेगेन यथास्वाभिमुखं भवेत्।।
पश्चात्तदुष्णवेगेन मण्यावरकपारदम्। गालयत्यतिवेगेन घनीभूतमतःपरम्।।
यावन्मात्रं गालयति मण्यावरकपारदम्। तावन्मात्रं रसस्स्वस्वरूपमासाद्य केवलम्।।
अवटे स्वपुरोभागस्थिते पतति वेगतः। तन्मणिष्षट्त्रिंशतिकसूक्ष्मदर्पणतस्ततः।।
वीक्ष्यते यदि तत्रत्यबिन्दुरेखांकनादयः। दृश्यन्ते हि यथापूर्वं तत्तत्संख्यानुसारतः।।
पारदोष्णं विनिश्चेतुमेतावन्मात्रमित्यतः। एवमुष्णापकर्षकतृणसंदर्शनादपि।।

Prose form:

अतः परं श्वेतदूर्वाकमलपुष्पक्षाराष्टकं, ताम्रषोडशके चूलीताम्रषोडशकं तथा द्वादश – स्वर्णलोहेषु हिरण्याष्टकं, गोदन्तीतालषट्कं, सूतपंचकं, सूर्यकान्तशिलाषट्कं एतान् भागशः संयोज्य क्रमात् माधिममूषायां संपूर्य, अथ यथाविधि कूर्मव्यासटिकां मध्ये स्थाप्य इंगालादिभिः द्वात्रिंशदुत्तर चतुश्शतकक्ष्योष्णमानतः गालयित्वा तद्रसं यंत्रमुखे संपूरयेत्। ततः उष्णापकर्षकं नाम कृतकं लोहं स्यात् तेन प्रकल्पितं भानुफलकं मधुवर्णकं निशाकरादर्शचक्रात् अपि न्यूनं षडंगुल–बिन्दु रेखांकनैःयुक्तम् अवटद्वयसंयुतं, प्रथमावटमध्यस्थपारदे संन्निवेशितं चतुष्षष्ट्युत्तरशतसंख्याकं भारवर्जितं, बिन्दुरेखांकनैःयुतम्, धर्मापहारकमणिं सुदृढसूक्ष्ममेरोः ऊर्ध्वं यथाविधि दधानं, क्रमात् द्वितीयरंध्रस्य दक्षदंडान्त्यकेन्द्रके त्रिचक्रकीलकैः यथा भ्राम्यते (तथा) सम्यक् स्थापयेत्। पश्चात् अवटे मणिसंयोगतः मणिं अन्तरतः कृत्वा निमिषार्धतः सूतकं घनत्वं याति। एतन् मणिः स्वशक्तितः सूर्यकिरणप्रकाशोष्णं यथास्वाभिमुखं भवेत् (तथा) अतिवेगेन समाकर्षति। पश्चात् उष्णं वेगेन घनीभूतं मण्यावरकपारदम् अतिवेगेन गालयति। अतः परं यावत् मात्रं मण्यावरकपारदं गालयति तावत् मात्रं रसः केवलं स्वस्वरूपम् आसाद्य स्वपुरोभागस्थिते अवटे वेगेन पतति। ततः तन्मणिः षट्त्रिंशतिक – सूक्ष्मदर्पणतः वीक्ष्यते। यदि तत्रत्य बिन्दुरेखांकनादयः यथापूर्वं तत्तत्संख्यानुसारतः दृश्यन्ते। इत्यतः एतावत् मात्रं पारदोष्णं विनिश्चेतुम् एवम् उष्णापकर्षकतृणसंदर्शनात् अपि (प्रकाशोष्णं विनिश्चेतुं शक्यम्)।

Now a fine mixture of 8 parts of potassium iodide (KI-*śvetadūrvākamala-kṣāra*), 16 parts of copper, out of sixteen grades of copper known as *'cūlītāmra'*, 8 parts of gold out of 12 grades of gold known as *hiraṇyaka*, 6 parts of arsenic sulphides (AsS_2, AsS_3-*godantitāla*), 5 parts of mercury (Hg. *sūta*) and 6 parts of quartz (SiO_2 *sūryakānta-śilā*) in a crucible *(māghima-mūṣā)* are melted into the furnace *(kūrma-vyāsaṭikā)* by fuel at 432 degree of temperature (of ancient scale) and then poured into a die *(yantramukha)*. This casted material *(Kṛtakam-loham)* is a material transparent to heat *(ūṣmāpakarṣaka)*. This material may be compared with Bernish gold). Afterwards above the second hole of the central pillar, a honey coloured circular plate made of this material, known as *bhānuphalaka*, graduated with lines, points, symbols etc. of diameter size less by 6 *aṅgula* than that of *Niśākarādarśa-cakra*, having two cavities, where in the first cavity infrared absorbing element (*gharmāpahāraka-maṇi* of serial number 164) with graduation marking is submerged into the mercury, is attached with pulley axis systems of the right side pillar meant for the very purpose, so that it *(bhānuphalaka)* may be rotated freely. In the first cavity due to the property of *'gharmāpahāraka-maṇi'* in no time mercury gets amalgamated and spreads over the lower surface of this *maṇi*. When the heat rays are incident over certain part of the upper surface of this element, due to its absorptive power, mercury of that part gets liberated from the amalgamated surface of this element. Therefore, this liberated mercury flows down towards the immediately close second cavity and where it gets collected. When this infrared absorbing element is inspected by a magnifying glass (*sūkṣmadarpaṇa* of serial number 36) from the graduations of this *maṇi* heat radiations are measured. As an alternative method, i.e. by the ignition of the 'heat absorbing grass' *(uṣmāpakarṣaka-tṛṇa)* the

heat radiations can also be measured.

Ancillary component 10:

पश्चाच्चतुर्दशोत्तरद्विशतेन यथाविधि। तमोगर्भा ख्यमणिना योजितं भारवर्जितम्।।
त्रिसप्तत्युत्तरशतात्मकं धूम्राकृतिं ततः। छायामुखादर्शचक्रं बिन्दुरेखांकनैर्युतम्।।
मेरोर्द्वितीयरंध्रस्थवामदण्डान्त्यकेन्द्रके। निशाकरादर्शचक्रस्याधस्तात्स्थापयेद्दृढम्।।
एतत्सूर्यप्रकाशस्थतमछायापकर्षणम्। कृत्वा विनिश्चीयते तत्प्रमाणं चांकनादिभिः।।

Prose form:

पश्चात् चतुर्दशोत्तरद्विशतेन यथाविधि तमोगर्भाख्यमणिनायोजितं भारवर्जितं, त्रिसप्तत्युत्तरशतात्मकं धूम्राकृतिं बिन्दुरेखांकनैः युतं छायामुखादर्शचक्रं मेरोः द्वितीय रंध्रस्थ वामदण्डान्त्य–केन्द्रके निशाकरदर्शचक्रस्य अधस्तात् दृढं स्थापयेत्। एतत् सूर्यप्रकाशस्थतमछायापकर्षणं कृत्वा तत् प्रमाणं च अंकनादिभिः विनिश्चीयते।

Then *'tamogrāhaka-maṇi'* of serial number 173 is fixed over a graduated circular plate known as *chāyāmukhādarśa-cakra* just below the second hole so that it may be revolved by the system fixed on the left side pillar. This transmits the ultraviolet radiations and the measurement is done with the help of graduations on it.

Ancillary component 11:

पश्चाद्द्विचत्वारिंशतिप्रभामणिनायुतम्। भागर्भादर्शवर्गस्थं षण्णवत्यात्मकं ततः।।
स्वच्छं प्रभामुखादर्शं बिन्दुरेखांकनैर्युतम्। मेरुस्तंभप्रथमरंध्रदक्षदण्डान्त्यकेन्द्रके।।
त्रिचक्रकीलकैस्सम्यक्स्थापयेद्भ्राम्यतेयथा। किरणोष्णप्रकाशांशं सूर्यस्येतत्स्वभावतः।।
पूर्वोक्तभानुफलकात्समाकृष्य स्वशक्तितः। निश्चीयते तत्प्रकाशप्रमाणं स्वांकनादिभिः।।

Prose form:

पश्चात् द्विचत्वारिंशतिक–प्रभामणिनायुतं, ततः भागर्भादर्शवर्गस्थं षण्णवत्यात्मकं ततः बिन्दुरेखांकनैः युतं स्वच्छं प्रभामुखादर्शं मेरुस्तम्भ – प्रथमरंध्रदक्षदण्डान्त्यकेन्द्रके त्रिचक्रकीलकैः यथा भ्राम्यते (तथा) सम्यक् स्थापयेत्। एतत् सूर्यस्य किरणोष्णप्रकाशांशं स्वभावतः पूर्वोक्त भानुफलकात् स्वशक्तितः समाकृष्य स्वांकनादिभिः तत् प्रकाशप्रमाणं निश्चीयते।

Again *prabhākara-maṇi* of serial number 42 is fixed over a graduated circular plate of serial number 96 *(bhāgarbhādarśa-cakra)* which is placed just above the right side of the first hole so that the *cakra* may be revolved with the help of a three pulley-axis system fixed at the right side of the central pillar. The sun has heat and light rays. This *maṇi* absorbs heat rays which are received through *bhānuphalaka*. The absorbed radiation measurement is done by the graduations on it.

Ancillary component 12:

स्तंभनामुखलोहेषु पश्चाद्द्वादशकस्य च। क्रमात्खचराख्यलोहस्याष्टभागांशकं तथा।।
भूचक्रसुरमित्रादिक्षारपञ्चकमेव च। अयस्कांतस्य चत्वारि षड्भागो रुरुकस्य च।।
एतान्संमेल्य विधिवत्तत्तद्भागानुसारतः। पश्चाद्भ्रामणिकमूषामुखमध्ये प्रपूर्य च।।
पञ्चषष्ट्युत्तरद्विशतकक्ष्योष्णप्रमाणतः। गालयित्वातिवेगेन यंत्रास्ये संप्रपूरयेत्।।
एतद्भवेत्कृतकलोहःप्रकाशस्तंभनाभिदः। तेन प्रकल्पितं चक्रं बिन्दुरेखांकनैर्युतम्।।
नवसंख्याकमणिना वल्लभाख्येन राजितम्। प्रकाशस्तंभनाचक्रं पञ्चाशीत्यात्मकं लघु।।
मेरुस्तंभप्रथमकेन्द्रवामदण्डान्त्यकेन्द्रके। त्रिचक्रकीलकैस्सम्यक्स्थापयेत्सुदृढंयथा।।
भागर्भदर्पणस्थितकिरणोष्णप्रकाशकम्। एतत्स्वशक्त्या बध्नात्यस्पन्दनं स्याद्यथाक्रमम्।।

Prose form:

पश्चात् स्तम्भनामुखलोहेषु द्वादशकस्य खचराख्यलोहस्य अष्टभागांशकं तथा भूचक्र-सुरमित्रादिक्षारपंचकम् अयस्कान्तस्य चत्वारि च रुरुकस्य षड्भागः, एतान् तत् भागानुसारतः विधिवत् संमेल्य पश्चात् भ्रामणिकमूषामुखमध्ये प्रपूर्य पंचषष्ट्युत्तरद्विशतकक्ष्योष्णप्रमाणतः गालयित्वा यंत्र (स्य) आस्ये अतिवेगेन प्रपूरयेत्। (तदा) प्रकाशस्तम्भनाभिदः एतत् कृतकलोहः भवेत् तेन बिन्दुरेखांकनैःयुतं चक्रं प्रकल्पितं (भवति) नवसंख्यामणिना वल्लभाख्येन राजितं प्रकाशस्तम्भनाचक्रं पंचाशीत्यात्मकं लघुमेरुस्तम्भप्रथमकेन्द्र–वामदण्ड्यात्मके केन्द्रके त्रिचककीलकैः सुदृढं यथा (भवेत्) तथा सम्यक् अवस्थापयेत्।

Then 8 parts of *'khacara-lauha'* or *vaidūrya* (probably silicon oxide, SiO_2) the 12th in the serial number in the group of radiation absorbing materials, 5 parts of *bhūchakra-sūryamitradi-kṣāra,* probably synonym of *śāligrāmaśilā* (calcium oxide, CaO), 4 parts of *ayaskānta* (magnetic oxide, Fe_3O_4) and 6 parts of *'ruruka'* (ash of dearbones, H_3PO_4) are mixed together in the ratio as given above and are melted in *bhrāmaṇika-mūṣā* (rotating crucible) at the temperature of 265 degree of the ancient temperature scale and then it is rapidly poured into the *yantra-mukha* (die). In this way *'prakāśa-stambhanābhida-lauha'* (heat absorbing material), is prepared.

Vallabha-maṇi of serial number 9 is fixed over a circular plate known as *prakāśa-stambhana-cakra* of serial number 96, casted as described above and graduated by points and lines, which is placed below the first hole so that it may be revolved, and setting may be done with the help of a three pulley-axle system fixed on the left side pillar from the first hole.

Ancillary component 13:

अथांजनिकदशकं धौम्यद्वादशकं तथा। नीलांजनं षोडशांशं चतुर्विंशांशकं रुरोः।।
जंवालिकास्थिदशकं शर्कराष्टकमेव च। चतुर्दशांशं सूतस्य नवांशं गैरिकस्य च।।
वराटिकापञ्चकं च तत्तद्भागानुसारतः। एतान्संयोज्यमूषायां संपूर्यविधिवत्क्रमात्।।

षड्विंशत्युत्तरपंचशतकक्ष्योष्णमानतः। गालयित्वाथयंत्रास्ये सेचयेद्यदिवेगतः।।
छायाप्रभाविभाजकलोहस्स्यात्कृतकस्ततः। तेन प्रकल्पितं छायाविभाजकपट्टिकम्।।
यावत्प्रमाणं चक्राणां षण्णामुभयपार्श्वयोः। तावत्प्रमाणं संक्लृप्तां पट्टिकां भारवर्जिताम्।।
मेरुस्तंभप्रथमरंध्राधोभागेयथाविधि। पार्श्वद्वयस्थचक्राणां संधिस्थाने न्यसेत्ततः।।

Prose form:

अथ अंजनिकदशकं तथा धौम्यद्वादशकं, नीलांजनं षोडशांशं, रुरोः चतुर्विंशांशकं, जम्बालिकास्थिदशकम् एव च शर्कराष्टकं, सूतस्य चतुर्दशांशं, गैरिकस्य नवांशं, तथा वराटिकापञ्चकं एतान् तत्तत्भागानुसारतः संयोज्य विधिवत् क्रमात् मूषायां संपूर्य षड्शिंत्युत्तरपंचशतकक्ष्योष्णमानतः गालयित्वा, अथ यंत्र (स्य) आस्ये यदि वेगतः सेचयेत्, ततः छायाप्रभाविभाजक–लोहः कृतकः स्यात्।

तेन प्रकल्पितं छायाप्रभाविभाजकपट्टिकां षण्णां चक्राणाम् उभयपार्श्वयोःयावत् प्रमाणं तावत् प्रमाणं संक्लृप्तां भारवर्जितां पट्टिकां मेरुस्तंभप्रथमरंध्राधोभागे पार्श्वद्वयस्थचक्राणां संधिस्थाने यथाविधि न्यसेत्। (ततः)

Chāya-prabhā-vibhājaka-lauha : 10 parts of *añjanika* (graphite-C), 12 parts of *dhaumya* (probably NH_4Cl), 16 parts of *nilāñjana* (Antimony sulphide) 16 parts of *ruruka* (ash of deer-bones), 10 parts of *jambālikāsthi* (ash of mud-plants, sodium and potassium halides), 9 parts *śarkarā* (sand SiO_2), 14 parts of *Sūta* (Mercury, Hg), 9 parts of *gairika* (Ferric Oxide Fe_2O_3) and 5 parts of *varāṭikā* (Calcium carbonate, $CaCO_3$) are mixed together and melted in the crucible at the temperatue 526 degree of ancient temperature scale and then rapidly poured into the die *(yantra-āsye)* to cast the *chāyā-prabhā-vibhājaka-lauha* (ultraviolet and visible differentiating material).

Now *chāyā-prabhā-vibhājaka paṭṭikā* (u v and v differentiating plate) made of the above material, which is a plate of shape having as if two circular plates joined together side by side of dimensions suitable to envelop the projections of all the six circular plates of either sides, as described earlier, is fixed at the base of *śaṅku* (central pillar) below the first hole.

Coating of right side round portion of the plate:

सूर्यकांताद्योषधीनां क्षारद्रावकतस्तथा। रक्तसुंडालकृष्णादिगरळद्रावकेन च।।
रविरंजिकशशिकादिलोहद्रावकादपि। रक्तसुंडालकृष्णादिगरलद्रावकेन च।।
दक्षभागं पट्टिकायास्सप्तवारं मुहुर्मुहुः। द्रावकत्रयतः पश्चात्पृथक्पृथग्विलेपयेत्।।
शोषयित्वा ततस्तस्मिन्नूपरद्रावकं पुनः। सेचयित्वा तदुपरि सुसूक्ष्मं कृष्णसैकतम्।।
विन्यस्य पश्चात्तन्मध्ये चित्रवर्णं मनोहरम्। त्रिसप्तत्युतरशतसंख्याकमतिसुन्दरम्।।
रवि चुंबकमणिं संधारयेत्सुदृढं यथा। एवंकृत्वा पट्टिकायास्संस्कारं दक्षपार्श्वके।।

Prose form

(ततः) सुर्यकान्ताद्योषधीनां क्षारद्रावकतः तथा रक्तसुंडाल कृष्णादिगरलद्रावकेन रविरंजिकशशिकादि– लोहद्रावकात् अपि पट्टिकायाः दक्षभागं सप्तवारं मुहुर्मुहः (लेपयित्वा) पश्चात् द्रावकत्रयतः पृथक् पृथक् विलेपयेत्। ततः शोषयित्वा तस्मिन् (दक्षभागे) ऊपरद्रावकं पुनः सेचयित्वा तत् उपरि सुसूक्ष्मं कृष्णसैकतं विन्यस्य पश्चात् तत् मध्ये त्रिसप्तत्युत्तरशतसंख्याकं चित्रवर्णं मनोहरम् अतिसुन्दरं रविं चुंबकमणिं सुदृढं संधारयेत्, एवं कृत्वा पट्टिकायाः दक्षपार्श्वके संस्कारं (भवति)।

Pastes made of *sūryakāntādīnām-kṣāra* (Al_2O_3), *rakta-suṇḍala-kṛṣṇādi-garala-drāvaka* (feric-ferocynides) and *ravi-rañjikā-śaśikādi-lauha-drāvaka* (salts of copper) are to be coated seven times. Then after, coating the plate by *uṣara drāvaka* (paste of alkali salts), *kṛṣṇa-saikata* (fine dark sand) is spread over the coatings. Afterwards a *citravarṇam, manoharam, atisundarm* (colourful, charming and beautiful) *ravicumbakamaṇi* (sun-rays sensor) is rigidly fixed. In this way right side portion of the plate is made ready for the use.

Preparation of the left side part of *Paṭṭikā:*
(probably coating of phosphorescent material for uv radiation).

वामपार्श्वस्य संस्काराः कथ्यतेऽथ यथाक्रमम्। कृष्णवल्ल्याद्योषधीनां क्षारद्रावकतस्तथा।।
घनगर्भादिलोहानां त्रयाणां द्रावकादपि। गौरीवीरादिगरळद्रावकैश्च यथाक्रमम्।।
मुहुर्मुहुस्सप्तवारं वामभागार्धपट्टिकाम्। लेपयित्वाथ संशोष्य पश्चात्तदुपरिक्रमात्।।
दुर्गंधकृष्णधान्यस्य चूर्णं संदापयेत्ततः। नीली चूर्णं तदुपरि निक्षिपेत्सप्रमाणतः।।
पश्चात्संसेचयेत्तस्योपरिताद्द्रावकेन च। तमोपकर्षकमणिं सप्तत्रिंशात्मकंशुचिम्।।
तस्य मध्ये यथाशास्त्रं स्थापयेदचलं यथा।

Prose form:

अथ यथाक्रमं (पट्टिकायाः) वामपार्श्वस्य संस्कारः कथ्यते–कृष्णवल्ल्याद्योषधीनां क्षारद्रावकतः तथा त्रयाणां घनगर्भादिलोहानां द्रावकात् अपि गौरीवीरादिगरलद्रावकैः यथाक्रमं वामभागार्धप–ट्टिकां मुहुर्मुहुः सप्तवारं लेपयित्वा, अथ संशोष्य पश्चात् तत् उपरिक्रमात् दुर्गंधकृष्णधान्यस्य चूर्णं संदापयेत्। ततः नीलीचूर्णं सप्रमाणतः तत् उपरि निक्षिपेत्। पश्चात् तस्य उपरि द्रावकेन सेचयेत्। (ततः) सप्तत्रिंशात्मकं शुचिं तमोपकर्षणमणिं तस्य मध्ये यथाशास्त्रम् अचलं स्थापयेत्।

The paste, which is prepared from the mixture of the alkali extract of either *chāyāmukulita-lājavatī* (mimosa) or *kṛṣṇa-citraka* or *bhṛṅgarāja* etc., acids of metal ashes of *ghanagarbha, svāntamukhī, kṛṣṇakāśisa* (MnO_2) or *sarpakṣī* (Serpentine) and the poisons like *Gaurī-vīra* (arsenic compounds) is coated seven times on the

left side circular plate. Then the powder of *durgandha-kṛṣṇa-dhānya* is spread over the plate and then *nīlīcūrṇam* in the last. Then *tamopakarṣaka-maṇi* (a sensor of u v radiation is placed at the centre).

पट्टिकादक्षभागस्य मणिःपश्चात्स्वशक्तितः।।
ऊर्ध्वभागस्थषट्चक्रैर्मेरोस्सम्यग्विभाजितम्। सूर्यकिरणप्रकाशं समाकृष्यातिवेगतः।।
पट्टिकादक्षभागेऽस्थ योजयेदचलं क्रमात्। वामपार्श्वस्थमणिरप्येवंवेगात्स्वशक्तितः।।
सूर्यकिरणप्रकाशस्थितच्छायापकर्षणम्। कृत्वा तद्वामभागस्य पट्टिकायां नियोक्ष्यति।।
एतेन किरणप्रकाशप्रमाणविनिर्णयः। पट्टिका दक्षिणे पार्श्वे वामपार्श्वे तथैव च।।
भवत्यंशुप्रकाशस्थछायाप्रमाणनिर्णयः।

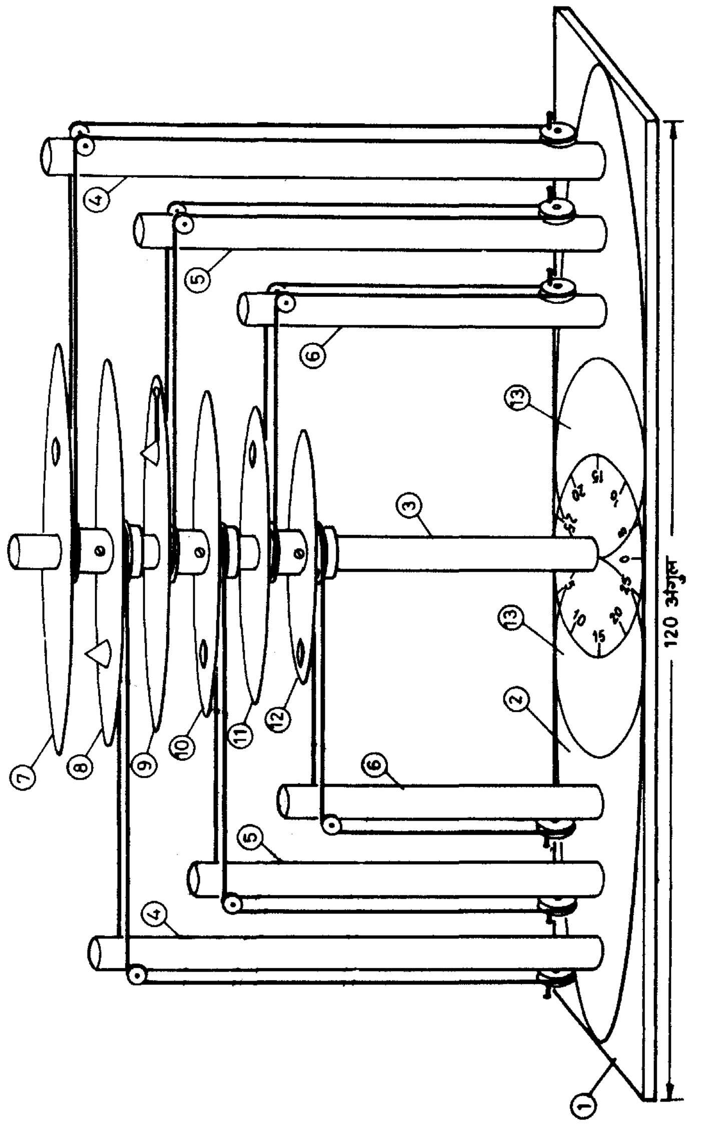
Prose form:

पश्चात् पट्टिकादक्षभागस्थमणिः स्वशक्तितः मेरोः ऊर्ध्वभागस्थषट्चक्रैः सम्यक् विभाजितं सूर्यकिरणप्रकाशम् अतिवेगतः समाकृष्य अथ पट्टिकादक्षभागे अचलं योजयेत्। क्रमात् वामपार्श्वस्थमणिः अपि एवं वेगात् स्वशक्तितः सूर्यकिरणप्रकाशस्थछायापकर्षणं कृत्वा तत् वामभागस्थ पट्टिकायां नियोक्ष्यति। एतेन किरणप्रकाशप्रमाणनिर्णयः (भवति)। पट्टिकादक्षिणे पार्श्वे तथा एव वामपार्श्वे अंशुप्रकाशस्थछायाप्रमाणनिर्णयः भवति।

By properly adjusting the six *cakra* which are capable to rotate about the central pillar, the emergent rays from the top right side lens (prabhākara maṇi) get dispersed *(Samyag-vibhājitam sūrya-kiraṇa-prakāśam)* and then they must be focussed on the right side plate. Similarly with the help of left side lens *(tamogarbhamaṇi)* which allows the *chāyā* (the ultraviolet radiation) present in sun rays, is focussed on the left side circular plate. Thus, with such arrangement visible radiations by the right side and ultraviolet radiations are measured by the left side.

Scientific Discussion

From the set up described (Fig. 1), it appears that the rays incident on the collimating lens *prabhākara-maṇi* of *'divākarādarśa-cakra'* (the ancillary component 7) and suffering dispersion through the prism *'Kiraṇa-grāhaka-maṇi'* or *'niśākarādarśa-cakra'* (the ancillary component 8), produce the first spectrum which must be comprised of spectral rings and not the spectral lines as observed in modern conventional prism spectrographs so that their centre lies on the graduated circular scale drawn on *'Chāyāpakarṣaṇādarśa'* (The ancillary component-2) and the angle observed at the intersection of the respective spectral ring becomes the same measure for the corresponding frequency. This requirement necessarily demands the shape of the prism to be a conical one. Keeping all these in mind one can draw a sketch as shown in Fig. 2 representing the essential elements of the instrument to workout the theoretical aspects.



महर्षि भरद्वाज का ध्वान्त (तम) प्रमापक यंत्र

FIG.1 NOVAL 'SPECTROMETER' OF MAHARṢI BHARADWAJA

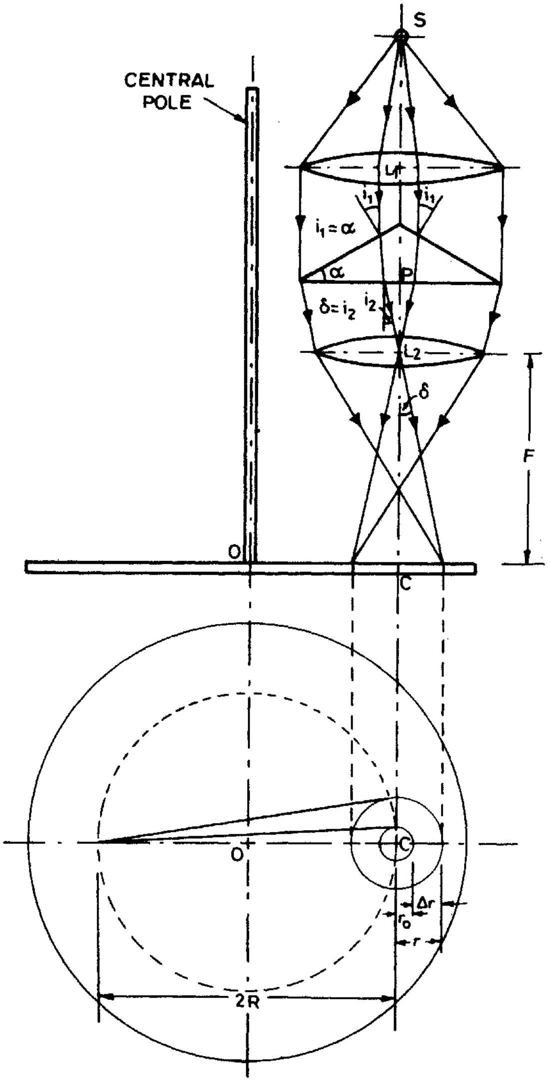


FIG. 2 THEORETICAL SCHEMATIC DIAGRAM OF DHWĀNTA PRAMĀPAK YANTRA

THEORY

Let the instrument consist of a co-axial arrangement of a pinhole S, collimating lens L_1, conical prism P as dispersing element, focussing lens L_2 and C be the screen.

The transmitted light through pinhole S is collimated by lens L_1 and the parallel beam of light falls on the conical prism P, which in turn gets dispersed and then focussed by lens L_2 in its focal plane at C. The resulting spectrum is comprised of concentric spectral rings with its centre at C. The graduated circular scale passes through C and its centre is at O which is the foot of the axis of the central pole.

For any prism of prism-angle A if the incident and emergent angles are i_1 and i_2 and the corresponding refracting and incident angles within the prism medium of refractive index, μ be r_1 and r_2 respectively, then applying Snell's law, we have

$$\mu = \frac{\text{Sin } i_1}{\text{Sin } r_1} = \frac{\text{Sin } i_2}{\text{Sin } r_2} \quad \text{where } r_1+r_2 = \alpha$$

For the present set up as shown in Fig. 2.

$\angle i_1 = \angle\alpha$ and $\angle i_2 = \angle\delta$ where $\angle\delta$ is the deviation for the spectral ring under consideration. After solving the equation for μ we have

$$\mu^2 = \text{Sin}^2\,\alpha + \left[\text{Cos }\alpha + \frac{\text{Sin }\delta}{\text{Sin }\alpha}\right]^2$$

Camparing with Cauchy's dispersion formula

$$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$ where A, B, C are the constants and λ is the wavelength of the spectral rings,

We have

$$\mu^2 = \text{Sin}^2\,\alpha + \left[\sqrt{A^2 - \text{Sin}^2\,\alpha} + \frac{AB}{\sqrt{A^2 - \text{Sin}^2\,\alpha}}\,\frac{1}{\lambda^2}\right]^2$$

$$\text{where } C = \frac{B^2\,\text{Sin}^2\alpha}{2A\,(A^2-\text{Sin}^2\alpha)}$$

therefore

$$\text{Sin }\delta = \text{Sin }\alpha\left[\sqrt{A^2 - \text{Sin}^2\,\alpha} - \text{Cos }\alpha + \right]\frac{AB\,\text{Sin }\alpha}{(\sqrt{A^2 - \text{Sin}^2\,\alpha})}\,\frac{1}{\lambda^2} \qquad \ldots\ldots. (1)$$

If $\delta = \delta_0$ for $\lambda = \infty$ or $\bar{\upsilon} = o$ where $\bar{\upsilon}$ is wave numer corresponding λ.

Then

$$\text{Sin } \delta_0 = \text{Sin } \alpha \, (A^2 - \text{Sin}^2 \alpha - \text{Cos } \alpha)$$

Substituting this value in equation (1) and rearranging we get

$$\frac{1}{\lambda^2} = \frac{A^2 - \text{Sin}^2 \alpha}{AB \text{ Sin } \alpha} (\text{Sin } \delta - \text{Sin } \delta_0) \quad \ldots\ldots. (2)$$

From Fig 2 if r and r_0 are the radii of the spectral rings for λ and $\lambda = \infty$ then $\text{Sin } \delta = \frac{r}{F}$ and $\text{Sin } \delta_0 = \frac{r_0}{F}$ were F is the focal length of the focussing lens. Substituting these values in equation (2) we have

$$\frac{1}{\lambda^2} = \frac{1}{F} \frac{\sqrt{A^2 - \text{Sin}^2 \alpha}}{AB \text{ Sin } \alpha} (r - r_0) = K^2 (r - r_0) \quad \ldots\ldots. (3)$$

$$\text{where } K = \left[\frac{1}{F} \frac{A^2 - \text{Sin}^2 \alpha}{AB \text{ Sin } \alpha} \right]^{1/2}$$

If the distances at the spectral rings pre measured from r_0 then

$$\Delta r = r - r_0$$

Substituting this value of Δ r in equation (3) we have

$$\boxed{\bar{\upsilon} = K \sqrt{\Delta r}}$$

Thus the wave number of the spectra ring is correctly proportional to the square root of the difference of the radius of the spectral ring concerned with that for the limiting value of $\bar{\upsilon} = 0$.

Antiquity of the Instrument

Bodhānanda in his commentary on *Aṃśubodhinī* has mentioned that the description of *Dhvāntapramāpaka-yantra* appearing in *Aṃśubodhinī* is adopted exactly in the same form as described by *Śārikānātha* in his work *Dhvānta-vijñānabhāskara,* which in turn is based on *Yantrasarvasva* of *Maharṣi Bharadvāja.* So, as far as the antiquity of the instrument is concerned, it is intersting to note the fact that even *Śārikānātha* belonged to at least 780-825 AD (*Prakaraṇa Pañcikā,* Banaras Hindu University, pp-56-57, 1961).

Conclusion

The above description of *Dhvāntapramāpaka-Yantra* reveals that

i) the nature and properties of the ultraviolet, visible and infrared radiations were well known in Ancient India,

ii) they knew the properties and methods of preparation of materials useful in such radiation studies and

iii) presumably also knew the theory and practice of this and other four types of spectrometer.

Above all, the instrument itself is an entirely new design of spectrometer not prevalent in modern scientific world.

Acknowledgement

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