# Mini-spectrometer from a DVD and folded paper

Writing up experiences with an open-source transmission grating spectrometer from DVD, paper and camera. **A very effective gadget to get hands-on training in spectroscopy!**

Practical application: it can be used for example to check the richness of LED lamp spectra in the shops.

Nice paper that can be downloaded via sci-hub.io: Wakabayashi "*A DVD Spectroscope: A Simple, High-Resolution Classroom Spectroscope*", Journal of Chemical education **83**, 56 (2006).

## Optical grating

Compared DVD and CD using a red laser pointer. CD gave 4 difracted beams, but DVD only one difracted beam. So DVD super useful for spectrometer. CD can store 800 MB but DVD 4.7 GB because of more dense tracks 1350 lines/mm instead of 625 lines/mm.


Fig.1. Comparison of diffraction patterns from a CD and from a DVD using a red laser pointer. https://www.youtube.com/watch?v=JLewHz7gUxE

Cutting the DVD with scisors and reflecting layer separation was not too hard. Usually the disk falls apart in two layers: reflective layer and the layer with the grating structure. So we are left with so called transmission difraction grating. The unprotected side with lines should not be touched with fingers as it is soft and can not be cleaned, similarly as when handling other diffraction gratings.

DVD spectrometer is affordable as it costs around 1 EUR. Commercial gratings used in research are on a thick flat glass substrate to prevent surface distortions and price starts at around 50 EUR.

## Paper enclosure

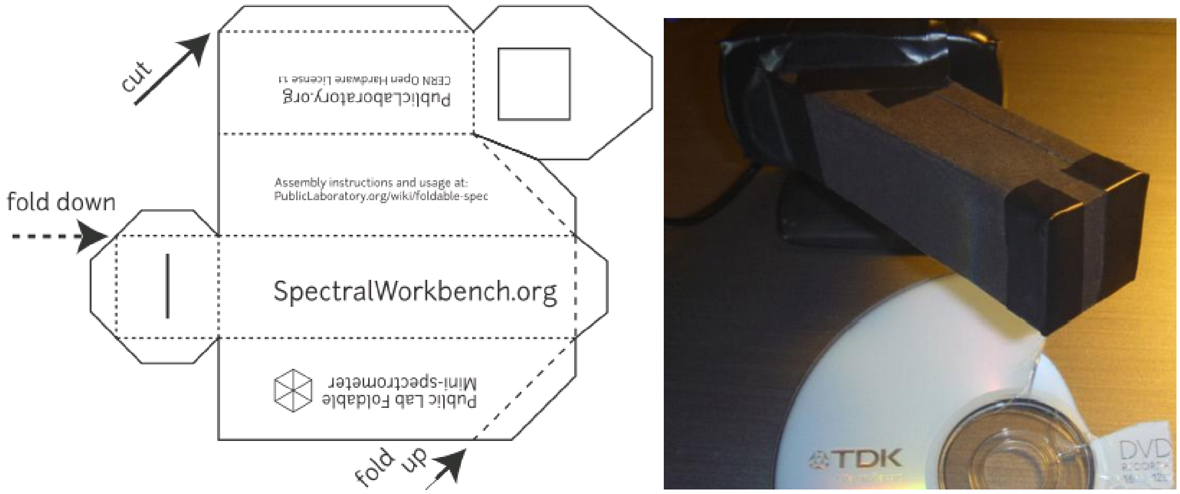



Fig. 2. Foldable paper spectrometer construction after downloaded plans from [https://publiclab.org/sites/default/files/8.5x11mini-spec3.8.pdf](https://publiclab.org/sites/default/files/8.5x11mini-spec3.8.pdf)

Printed the drawing on a A4 paper page, glued it onto thick black paper and cut with a knife. Used the tip of the knife to score bending places. Glued with some sticky glue or superglue. Superglue needs more care as it can leave evaporation stains. Some black tape was needed to stop the light leakage from the corners.

Spectrometer can be tested by bringing it close to an eye. I pointed the input slit to the CFL lamp and saw beautiful spectral lines of the mercury and flourophores. Eye has higher dynamic range and spacial resolution than a camera. It does not need batteries eather and you can see the true colors.

Eye resolves Hg doublet separated by 2 nm at 577 nm and 579 nm. CFL lamp spectra differ significantly as luminophor composition varies. There are so called warm and cold tone lamps. Phosphorous spectra are broadband but also have some sharper feartures.

In the daylight spectrum can resolve nicely many Fraunhofer dark lines by the elements present in the solar atmosphere!

Looking at the the yellowish Na high-pressure lamps used for street lightning was a surprise. Instead of a bright line at 589 nm it was dark and broad due to the re-absorption effect. The spectrum was actually quite rich in colors, not just the yellow color as I expected before.

## Obtained spectra and fine alignment

In the paper spectrometer instructions was no comment about the reccomended width of the input slit. Tried to optimize it with some tape. Best result was with the slit slightly tapered. On the wider end was coming through more light, but on the narrower end obtained sharper spectral lines.

Before gluing the exit window holding DVD to the black tube need to look at a CFL and align so that the input slit is paralell to the grating lines to get as narrow spectral lines as possible and to be able to resolve doublet of 577 & 579 nm. Lines broaden if the input slit is not paralell to the  grating lines.

Webcam lens lacked focusing adjustment to focus on the input slit. Tried a photo camera and got much better result compared to a phone.

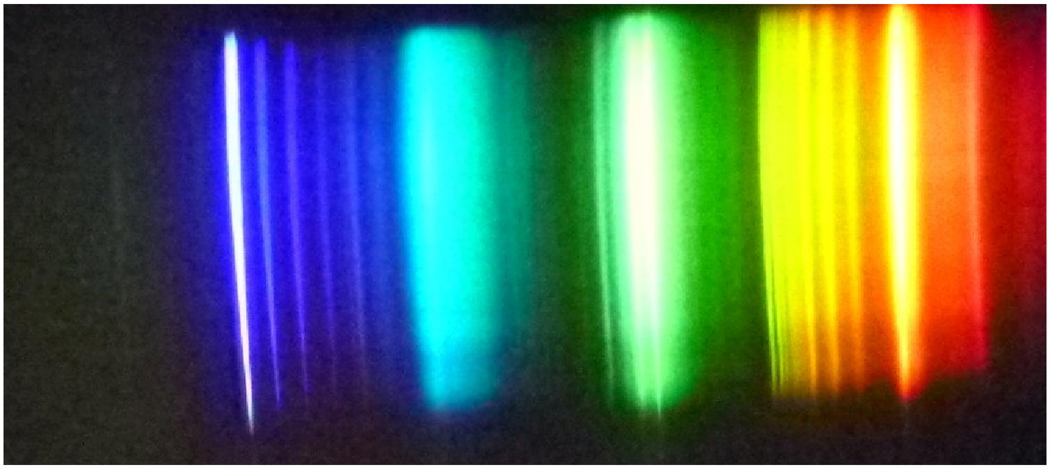


Fig.3.  Tried a photo camera and got much better result than with a webcam.
Noted that 405 nm line is missing on a photo camera due to a built-in color filter.

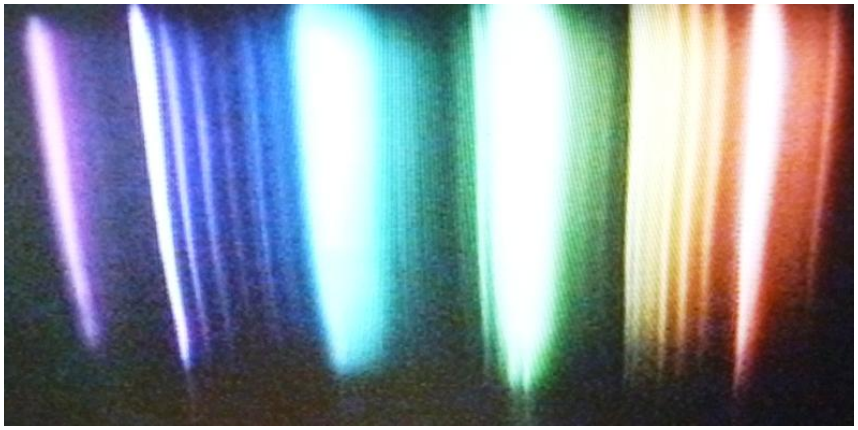


Fig.4. Analog survilance TV camera. Large zoom lens. Indeed **manual focus fine adjustment** is very critical. Colors of the spectral lines that PC displays depend on camera and can differ quite a lot from observed by an eye.

## Process the image to a graph spectrum

https://spectralworkbench.org/capture

No installation on PC or phone needed. Opens a camera window in webbrowser. There is possibility to upload pictures to cloud. Callibrate spectrum button does not to work until first spectrum is not uploaded to your account and processed there.

**On Android phone only front camera was active and I could not switch to the back camera. Fixing to the LG phone with a tape blocked the power on button.  So I decided to abandon Android and try a webcam connected to a PC.**

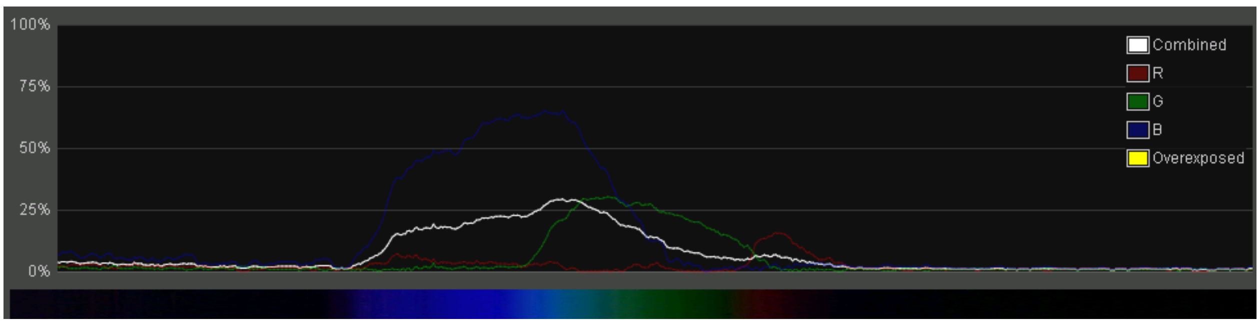



Fig. 5. Daylight spectrum. Can see blue green and red camera pixel responce and the sum of them in white color. Correctly would be to use a black and white camera sensor having uniform spectral responce.

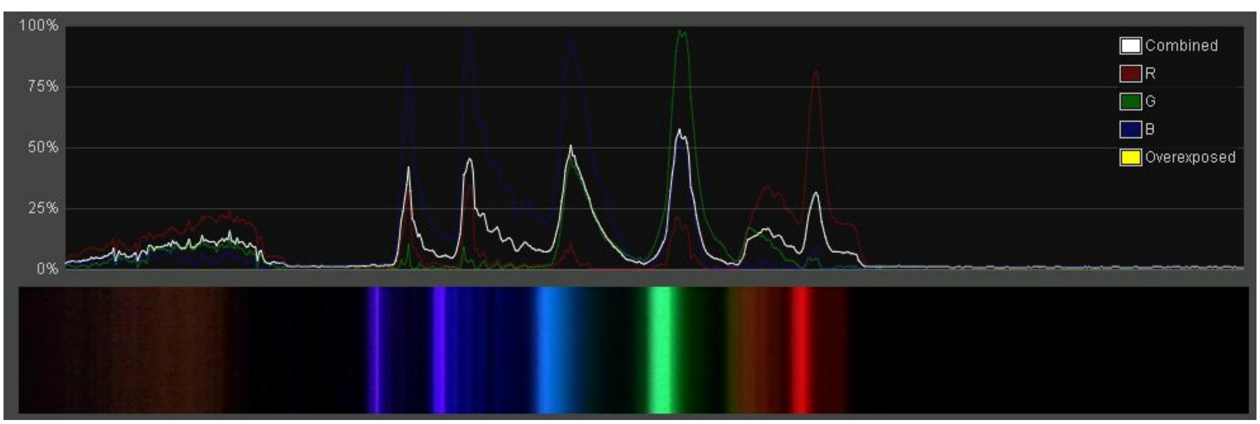



Fig.6. Spectrum of a CFL lamp. On the left side is some ghost spectrum that should not be there as lamp glass should not transmit UV. Could it be be light reflection from paper surface or second order effect? **There is a bug as spectrum waterfall display lines are shifted to the left compared to the spectrum graph.**

## Comparing with the online data

Table. Hg line values from a NIST database. Lines marked with II belong to double-ionised Hg and I could not observe in the CFL.

| | | | |
|---|---|---|---|
| 600 | 3650.153 | Hg I | UV, can't see by eye |
| 70 | 3654.836 | Hg I | UV, can't see by eye |
| 50 | 3663.279 | Hg I | UV, can't see by eye |
| 1000 | 3983.931 | Hg II | not observed, double-ionized Hg |
| 400 | 4046.563 | Hg I | Strong violet |
| 60 | 4339.223 | Hg I | |
| 100 | 4347.494 | Hg I | |
| 1000 | 4358.328 | Hg I | Strong blue |
| 12 | 5128.442 | Hg II | not observed |
| 15 | 5204.768 | Hg II | not observed |
| 80 | 5425.253 | Hg II | not observed |
| 500 | 5460.735 | Hg I | |
| 200 | 5677.105 | Hg II | not observed |
| **50** | **5769.598** | **Hg I** | **Doublet spaced by 2 nm** |
| **60** | **5790.663** | **Hg I** | **Doublet spaced by 2 nm** |
| 12 | 5871.279 | Hg II | not observed |
| 20 | 5888.939 | Hg II | not observed |
| 15 | 6146.435 | Hg II | not observed |
| 250 | 6149.475 | Hg II | not observed |
| 25 | 7081.90 | Hg I | |
| 6 | 7346.508 | Hg II | not observed |
| 250 | 7944.555 | Hg II | not observed |

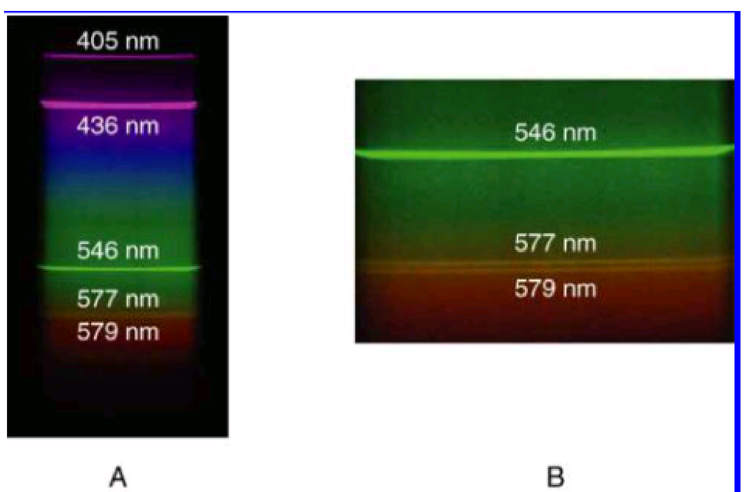



Figure 4. Visible spectrum of a traditional fluorescent lamp observed with the DVD spectroscope: (A) whole spectrum and (B) in the region of 578 nm.

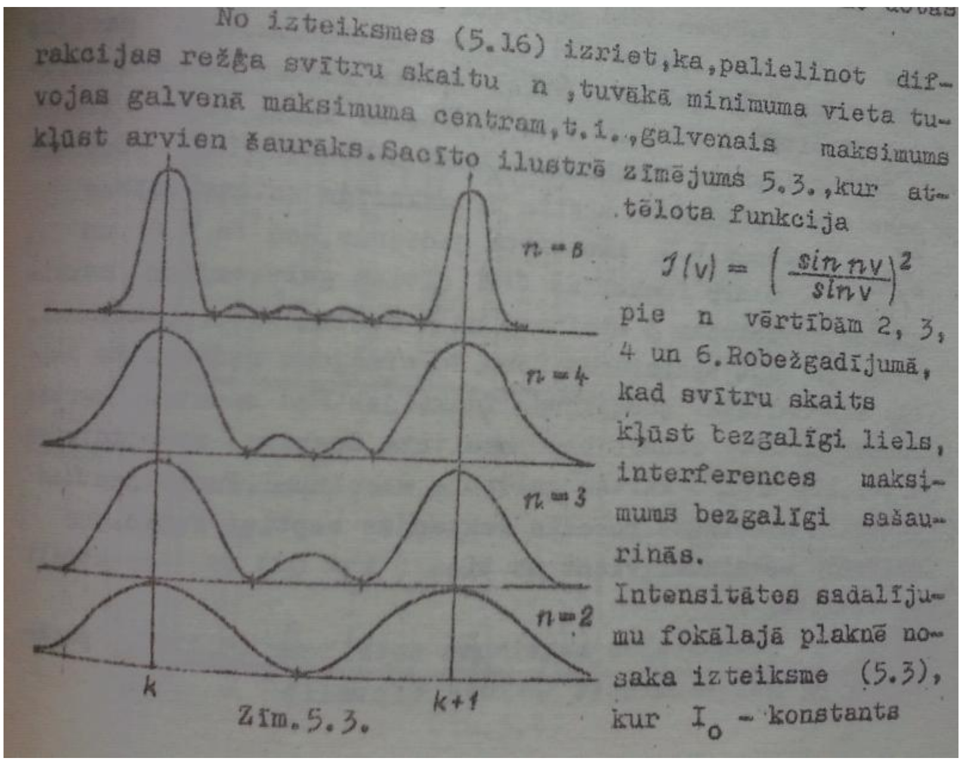
Fig 7. Spectrum from Wakabayashi "A DVD Spectroscope: A Simple, High-Resolution Classroom Spectroscope", Journal of Chemical education **83**, 56, (2006). Hg lines spaced 2 nm apart are resolved .

## Resolution of a grating spectrometer

It took a while to understand how good is the spectral resolution of such DVD spectrometer.

Increasing the number of illuminated grating lines increases the spectral resolution. Suppose we have a source emmiting two spectral lines. As the number of slits increases we would get more narrow lines and less background. The background has suppressed peaks. The number of the suppressed peaks is equal to the number of illuminated grating lines -1.

The resolution $\boldsymbol{R} = \lambda / \Delta\lambda$ = number of illuminated grating lines or slits. This shows how good we can split the region around the center wavelength λ.



No izteiksmes (5.16) izriet,ka,palielinot difrakcijas režģa svītru skaitu n ,tuvākā minimuma vieta tuvojas galvenā maksimuma centram,t.i.,galvenais maksimums kļūst arvien šaurāks.Sacīto ilustrē zīmējums 5.3.,kur attēlota funkcija

$$J(v) = \left(\frac{\sin nv}{\sin v}\right)^2$$

pie n vērtībām 2, 3, 4 un 6.Robežgadījumā, kad svītru skaits kļūst bezgalīgi liels, interferences maksimums bezgalīgi sašaurinās.

Intensitātes sadalījumu fokālajā plaknē nosaka izteiksme (5.3), kur $I_0$ - konstants



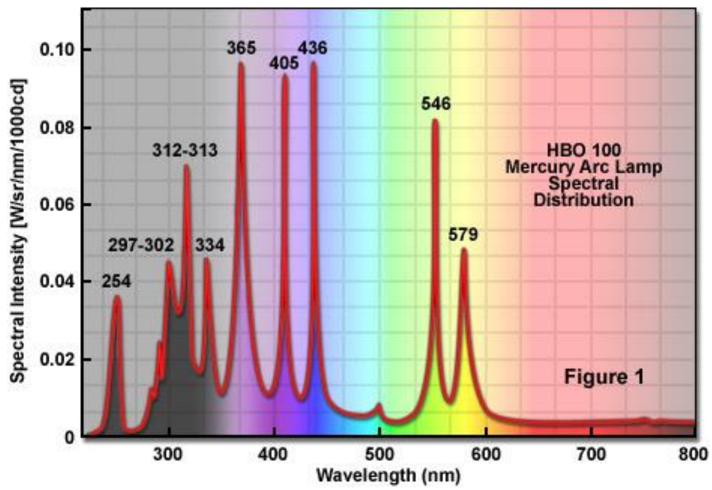
Fig. 8. Diffraction patterns as the number of illuminated grating slits increases. Latvian textbook.

Now lets calculate how large grating size we need to illuminate. For example Na atoms emmit so called D-doublet at 589.0 nm and 589.6 nm and one needs to resolve 0.6 nm. It is better that the spectrometer resolution is slightly better, lets say 0.1 nm.
**500nm / 0.1 nm = 5000.** This is the required resolution and the number of lines lines to be illuminated. DVD track spacing is 1350 lines/mm so we need to illuminate around least **4 mm** wide spot. If one photographs it then the camera lens should be ca 5 mm in diameter because it is round and not rectangular.

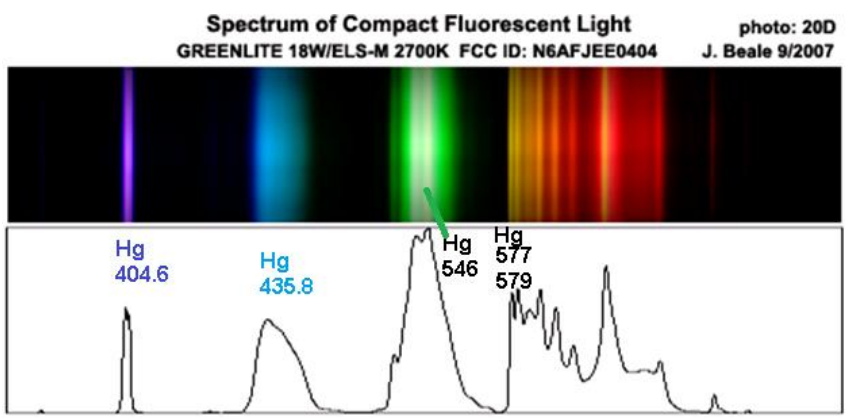
Resolution can also limited by the angular resolution of the eye. If a camera is used then by the pixel size. Resolution can also be limited by geometrical factor the input slit width and distance to a grating. 10cm/0.1mm gives the resolution limit of 1000. That is why good spectrometers are usually large boxes.

## Appendix

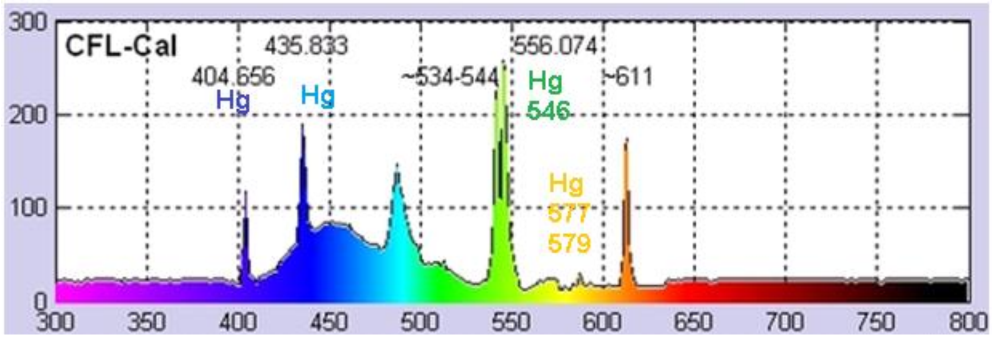
## Collection of Hg and CFL spectral examples from the Internet



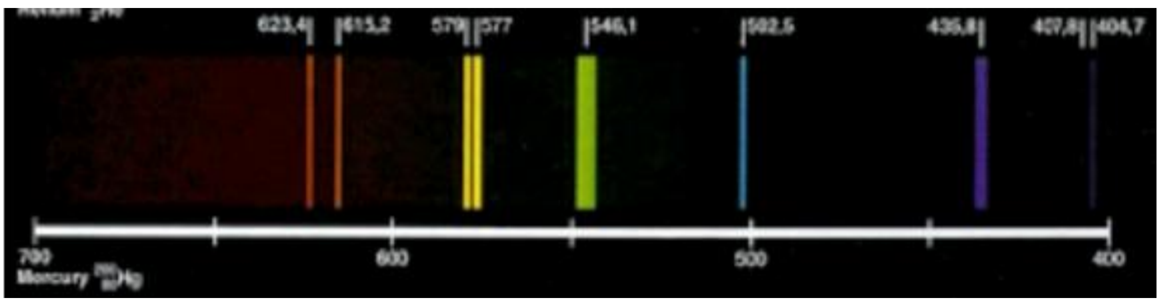

In this spectrum showing UV part in detail, the lines 577 and 579 nm lines are not resolved.




Example of a CFL spectrum. CFL lamp spectra differ significantly as luminophor composition varies. There are so called warm and cold tone lamps. There are broad phosphorous absorpion bands.




In this spectrum I inserted color letters Hg. 546 nm was originally not in the picture. 577 and 579 nm are only barely visible.




In this spectrum, 623.4 and 615.2 and 502.6 nm are not Hg lines, see NIST table .