How physicist can find ideas in National Palace Museum?

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Understanding **qi-wa**, the curling of scrolled artwork. In the Chinese and other traditions, paintings are executed on long paper or silk scrolls. On display, those artworks may be plagued by **qi-wa**, a curling up of the side edges that can tear fibers and dislodge pigment. Many analyses to date of **qi-wa** have focused on such factors as environmental humidity or the glue used to affix a painting to its mounting. But a group of Taiwanese physicists and conservationists led by Tzay-Ming Hong of National Tsing Hua University have shown that **qi-wa** can be explained by a physical mechanism put into play when the art is rolled up for storage. Rolling compresses the inner, painted face of the scroll in the long direction and stretches the outer face. When the scroll is removed from storage, the strain relaxes. As a result of the Poisson effect, the compressed face swells, causing the sides of the scroll to curl up.
Curling Edges: A Problem that Has Plagued Scrolls for Millennia

Ming-Han Chou,1 Wei-Chao Shen,1 Yi-Ping Wang,1 Sun-Hsin Hung,2 and Tzay-Ming Hong1,3,*

1Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan, Republic of China
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(Received 25 August 2013; published 23 January 2014)

Qi-Wa refers to the up curl on the lengths of hand scrolls and hanging scrolls, which has troubled Chinese artisans and emperors for as long as the art of painting and calligraphy has existed. This warp is unwelcome not only for aesthetic reasons, but its potential damage to the fiber and ink. Although it is generally treated as a part of the cockling and curling due to moisture, consistency of paste, and defects from the mounting procedures, we demonstrate that the spontaneous extrinsic curvature incurred from the storage is in fact more essential to understanding and curing Qi-Wa. In contrast to the former factors whose effects are less predictable, the plastic deformation and strain distribution on a membrane are a well-defined mechanical problem. We study this phenomenon by experiments, theoretical models, and molecular dynamics simulation, and obtain consistent scaling relations for the Qi-Wa height. This knowledge enables us to propose modifications on the traditional mounting techniques that are tested on real mounted paper to be effective at mitigating Qi-Wa. By experimenting on polymer-based films, we demonstrate the possible relevance of our study to the modern development of flexible electronic paper.

DOI: 10.1103/PhysRevLett.112.034302  PACS numbers: 46.32.+x, 46.70.De
凡煮糊，必去筋，稀缓得所，搅之不停，自然调熟。
———《历代名画记》

裱工用糊如用水，止在多刷，刷多则浆水沁透纸，凝结如抄成者，不全恃糊力矣
———《装潢志》

裱房恶地湿而惮风燥，喜温润而爱虚明。装板须高，利画坚固。必安地屏，杜湿上蒸。
———《装潢志》

装潢书画，秋为上时，春为中时，夏为下时，暑湿及凝寒俱不可装裱
———《长物志》

上壁宜润，贵其湿润，下壁宜燥，庶平瓦患，燥润失宜，优劣籍焉。
———《装潢志》

Paste, mounting skills, humidity, weather, etc.
Collaborators

Ming-Han Chou（周明翰，清大物理系）
Wei-Chao Shen（沈維昭，清大物理系）
Yi-Ping Wang（汪依平，清大物理系）
Sun-Hsun Hong（洪順興，國立故宮博物院）
Outline

• Introduction (15 min.)
• Curling edges on scrolls, aka Qi-Wa 起瓦 (5 min.)
• Background knowledge on mounting (5 min.)
• Experiment, theoretical model, and MD simulation (10 min.)
• Remedies to mitigate Qi-Wa (5 min.)
• Conclusions and discussions (5 min.)
Introduction (15 min.)

• Curling edges on scrolls, aka Qi-Wa (5 min.)
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• Conclusions and discussions (5 min.)
Gutenberg-Richter law

\[ N = 10^{a-bM} \]
Ubiquity of power law

1. Pareto’s law of income distribution, aka 80-20 rule
2. Number of cities having a certain population
3. Sizes of earthquakes
4. Sizes of craters on the moon
5. Sizes of solar flares
6. Foraging pattern of various species
7. Activity patterns of neuronal populations
8. Frequencies of words in most languages
9. Frequencies of family names
10. The species richness in clades of organisms
11. Sizes of power outages
12. Sizes of war
13. Criminal charges per convict
Sand pile explains it all?
Crackling noise

James P. Sethna*, Karin A. Dahmen† & Christopher R. Myers‡

*Laboratory of Atomic and Solid State Physics, Clark Hall, Cornell University, Ithaca, New York 14853-2501, USA (sethna@lassp.cornell.edu)
†Department of Physics, 1110 West Green Street, University of Illinois at Urbana-Champaign, Illinois 61801-3080, USA (dahmen@physics.uiuc.edu)
‡Cornell Theory Center, Frank H. T. Rhodes Hall, Cornell University, Ithaca, New York 14853-3801, USA (myers@tc.cornell.edu)

Crackling noise arises when a system responds to changing external conditions through discrete, impulsive events spanning a broad range of sizes. A wide variety of physical systems exhibiting crackling noise have been studied, from earthquakes on faults to paper crumpling. Because these systems exhibit regular behaviour over a huge range of sizes, their behaviour is likely to be independent of microscopic and macroscopic details, and progress can be made by the use of simple models. The fact that these models and real systems can share the same behaviour on many scales is called universality. We illustrate these ideas by using results for our model of crackling noise in magnets, explaining the use of the renormalization group and scaling collapses, and we highlight some continuing challenges in this still-evolving field.
Power laws for energetics

Tom Witten, Chicago
Ridge length distribution

\[ \frac{1}{x\sqrt{2\pi\sigma}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}} \]
Average ridge length and number
Crumpling noises
Gutenberg-Richter law

\[ N = 10^{a-bM} \]
Co-crumpling
Crackling noise

James P. Sethna*, Karin A. Dahmen† & Christopher R. Myers‡

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<td>• Conclusions and discussions (5 min.)</td>
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Collection of scrolls in National Palace Museum, Taipei dated back to the Six Dynasties (222-589)

女史箴圖 顧愷之(345-406)
凡煮糊，必去筋，稀緩得所，攪之不停，自然調熟。
——《歷代名畫記，唐 張彥遠》

良工用糊如用水，止在多刷，刷多則漿水沁透紙，凝結如抄成者，不全恃糊力矣…上壁宜潤，貴其滋潤，下壁宜燥，庶平瓦患，燥潤失宜，優劣繫焉…裱房惡地濕而憚風燥，喜溫潤而愛虛明。裝板須高，利畫堅挺。必安地屏，杜濕上蒸。
——《裝潢志，明 周嘉胄》

裝潢書畫，秋為上時，春為中時，夏為下時，暑濕及凝寒俱不可裝裱。
——《長物志，明 文震亨》
Traditionally Qi-Wa is treated as a part of cockling and curling due to moisture, consistency of paste, and defects from mounting procedures.
We demonstrate that spontaneous extrinsic curvature incurred from storage is more essential
In contrast to conventional factors whose effects are less predictable, plastic deformations due to spontaneous curvature are a well-defined mechanical problem.
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- Remedies to mitigate Qi-Wa (5 min.)
- Conclusions and discussions (5 min.)
Mounting is an old trade with strict traditions and aesthetic standards (and tons of jargons)
Chinese v.s. Japanese mounting

裱件組成：四紙三漿

中式

<table>
<thead>
<tr>
<th>裏打</th>
<th>織維長度</th>
<th>織維方向性</th>
<th>接紙方式</th>
<th>接紙貼法</th>
<th>覆背紙材</th>
</tr>
</thead>
<tbody>
<tr>
<td>無</td>
<td>有</td>
<td>有</td>
<td>邊緣重疊</td>
<td>不規則</td>
<td>宣紙</td>
</tr>
</tbody>
</table>
| 日式
| 覆背紙材 | 織維長度 | 織維方向性 | 接紙方式   | 接紙貼法 | 裏打 |
| 楮皮紙 | 長       | 有         | 毛邊接合   | 規則     | 有       |

中式裝裱和日式裝裱比較

中式

日式

裱件組成: 四紙三漿
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• Conclusions and discussions (5 min.)
Home-built profilometer
Qi-Wa height v.s. width of scroll

![Graph showing Qi-Wa height versus width of scroll](image)
Theoretical models

\[ h \sim \left( \frac{K_c}{K_{\perp}} \right)^{1/4} L \sqrt{\nu \phi t} \]

\[ h \sim \left( \frac{K_{\perp}}{K_c} \right)^{1/8} \sqrt{L} (\nu \phi)^{3/4} t^{1/4} l \]
Molecular Dynamics simulations

Triangular lattice

(Bending energy)

(stretching energy)

(L-J 12-6 potential)
U-shaped scroll

\[ h \approx \left( \frac{K_{S2\perp}}{K_{S1\parallel}} \right)^{1/4} \left( \nu \phi t \right)^{1/2} \cdot L \]

<table>
<thead>
<tr>
<th>U-shape</th>
<th>L</th>
<th>I</th>
<th>( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>0.9</td>
<td>0.069</td>
<td>0.6</td>
</tr>
<tr>
<td>Paper</td>
<td>0.85</td>
<td>-0.133</td>
<td>0.5</td>
</tr>
<tr>
<td>M.D</td>
<td>0.8</td>
<td>-0.013</td>
<td>0.4</td>
</tr>
</tbody>
</table>
V-shaped scroll

\[ h \approx \left( \frac{K_{S1\perp}}{K_{S2\parallel}} \right)^{1/8} L^{1/2} (\nu\phi)^{3/4} \ell^{1/4} \]

<table>
<thead>
<tr>
<th>V-shape</th>
<th>L</th>
<th>I</th>
<th>( \phi )</th>
</tr>
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<tr>
<td>PET</td>
<td>0.53</td>
<td>0.96</td>
<td>0.47</td>
</tr>
<tr>
<td>Paper</td>
<td>0.36</td>
<td>0.9</td>
<td>0.43</td>
</tr>
<tr>
<td>M.D</td>
<td>0.8</td>
<td>1.04</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Check the K-dependence

$$h \approx \left( \frac{K_{S2\perp}}{K_{S1\parallel}} \right)^{1/4}$$

$$h \approx \left( \frac{K_{S1\perp}}{K_{S2\parallel}} \right)^{1/8}$$
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Remedies to mitigate Qi-Wa

1. Reorient main fiber direction to parallel the length
2. Increase border thickness
3. Perforate backing paper with a stiff brush
4. Change patching pattern
5. Increase roller radius
(a) Align fiber directions  
(b) Adding layers of width $\ell/2 - x$ to side borders  
(c) Poking
• Introduction (15 min.)
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Conclusions

1. Moisture, paste, and mounting techniques are important to prevent cockling, but spontaneous \textit{curvature is more essential} to causing Qi-Wa.

2. Instead of relying on experience and luck, we propose a \textit{scientific method} to treat Qi-Wa.

3. Our model for curling edges is general and can be \textit{applied to flexible electronic paper}.
CHAPTER I

Down the Rabbit-Hole

Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do. "Oh! my dears, if I had only something to be doing!" she said, more to herself than to her sister; and her sister said nothing, because she always said nothing.

But she was not at all sure that there was anything else that she could have done: indeed, it was very doubtful whether there was anything in the world that Alice could have done, except thinking "Oh! my dears, if I had only something to be doing!"

So she was considering in her own mind (as well as she could, for the hot day made her feel very sleepy and stupid), whether the pleasure of making a merry-chap would be worth the trouble of getting up and picking the dozes, when suddenly a White Rabbit with pink eyes ran close by her.

There was nothing so VERY remarkable in that: nor did Alice think it so VERY much out of the way to hear the Rabbit say to itself, "Oh dear! Oh dear! I shall be late!" when she thought it over after.
Synopsis: Modern Recipe for Preserving Ancient Chinese Scrolls

Curling Edges: A Problem that Has Plagued Scrolls for Millennia
Ming-Han Chou, Wei-Chao Shen, Yi-Ping Wang, Sun-Hsin Hung, and Tzay-Ming Hong
Published January 23, 2014

As art conservators know, long-term storage of rolled up scrolls—such as ancient Chinese paintings and calligraphy—can cause the long edges of the paper to curl outwards, with potentially damaging effects. Ming-Han Chou and researchers at National Tsing Hua University in Taiwan, now have a theory for what causes this curling, known in Chinese as Qi Wa (起瓦). Their model, presented in Physical Review Letters, could help conservators find better ways to prepare and store the artworks, and it may be applicable to biological membranes or other flexible materials.
Curling Edges: A Problem that Has Plagued Scrolls for Millennia

Ming-Han Chou,¹ Wei-Chao Shen,¹ Yi-Ping Wang,¹ Sun-Hsin Hung,² and Tzay-Ming Hong¹,3,*

¹Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan, Republic of China
²Department of Registration and Conservation, National Palace Museum, Taipei 11143, Taiwan, Republic of China
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(Received 25 August 2013; published 23 January 2014)

Chinese painting [1–4] has a long history of tradition and styles in arranging human figures, animals, landscape, and plants into one or multiple themes as in symphonies. The collections of painting scrolls in the National Palace Museum in Taipei, Taiwan can be dated back to the Six Dynasties (222–589). The modes of landscape painting started in the Five Dynasties period (907–960) and have enjoyed many variations through the years. For instance, emphasis was shifted in the Song Dynasty (960–1279) from grand mountains and waterfalls to more intimate depictions as a result of the political and cultural shift to south China. Catering to the tastes of emperors, painters also adjusted their focus on observing nature infused with poetic sentiments to expressing inner feelings. This focus on poetic sentiment led to the combination of painting, poetry, and calligraphy in the same work by the Southern Song (1127–1279). Subsequent movements include the literati [5] painting in the Yuan Dynasty (1279–1368), and concentration on personal cultivations and the establishment of separate local schools in the Ming (1368–1644) and Qing (1644–1911) Dynasties.
ScienceShot: How to Save Your Scroll

30 January 2014 12:45 pm | 0 Comments
Understanding *qi-wa*, the curling of scrolled artwork. In
the Chinese and other traditions, paintings are executed
on long paper or silk scrolls. On display, those artworks may
be plagued by *qi-wa*, a curling up of the side
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by a physical mechanism put into play when the
art is rolled up for storage. Rolling compresses
the inner, painted face of the scroll in the long
direction and stretches the outer face. When the
scroll is removed from storage, the strain relaxes.
As a result of the Poisson effect, the inner
face of the scroll will curl upward and the outer
face will curl downward, curling *qi-wa*.
Save ancient Chinese scrolls with anti-curl weapons

19:10 28 January 2014 by Jacob Aron

Ancient Chinese scrolls may solve a dilemma for futuristic electronics: how to avoid curling. Hanging scrolls traditionally used in Chinese paintings are normally stored rolled up to protect their delicate artwork. But when unrolled, the long sides will curl, potentially causing damage.

Tzay-Ming Hong at the National Tsing Hua University in Taiwan and his colleagues decided to investigate curling scrolls after a trip to the National Palace Museum in Taipei, where they talked to art conservationists about ways to use physics to protect hanging scrolls. “Like the mounting masters before them, over the span of more than 2000 years, they did not think this problem was at all solvable,” says Hong.

The team modelled the problem on computers and with real paper and plastic films. They found that rolling causes the back layer of a scroll to stretch along its length. This means the paper shrinks back when the scroll is laid out flat, causing it to expand along its width and curl.

Rolled scrolls protect, but often at the cost of...
Posters, panoramic high school photos, ancient scrolls... they’re all plagued by the same problem. Curling edges. I usually just roll it up from the opposite side, but that leaves its own unsightly creases.

Now, physicists from Taiwan have found a way to save paper from this unwelcomed warping. And they think their method could help with the development of flexible electronics.
CURLING EDGES: A PROBLEM THAT HAS PLAGUED SCROLLS FOR MILLENNIA
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9. 沈維昭等，起瓦—困擾書畫收藏家數百年的物理現象，科學發展493期，38頁(2014)
Scaling relation for a compact crumpled thin sheet

Wubin Bai, Yen-Chih Lin, Tzon-Kun Hou, and Tzay-Ming Hong
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(Received 9 August 2010; revised manuscript received 16 November 2010; published 10 December 2010)

A high-pressure chamber was designed to study crumpling beyond the power-law regime. Preceded by a smooth transition, the crumpled ball that characterizes the high-pressure state contains less than 50% air and exhibits separate ordered domains. All data for different sheet thicknesses, sizes, and numbers were found to collapse to a master line when using volume ratio and pressure as the plotting parameters, which suggests the existence of a scaling relation. Based on these findings, we deduced a bundled-layer model that could consistently explain six outstanding properties at both low and high pressures. This successful union of theory and experiment has strong bearings on other soft-matter systems where similar changes in mechanical response are also linked to reorganization of structure.

DOI: 10.1103/PhysRevE.82.066112

the sample with an isotropic force. The thin film adopted is latex, which is commonly used to produce condoms and ideal for preventing leakage of fluids. To monitor the leakage