FTPI-MINN-XX/XX, UMN-TH-XXXX/XX
August 18/2014/DRAFT

Appendix only

A Notations

{app:notations

A.1 Twisted superfields

Twisted superfields exist in two dimensions and are defined by a "twisted" chirality condition

$$D_L \Sigma \;=\; \overline{D}_R \Sigma \;=\; 0\,. \tag{A.1}$$ {gentwist}

Analogously, for twisted anti-chiral superfields,

$$D_R \overline{\Sigma} \;=\; \overline{D}_L \overline{\Sigma} \;=\; 0\,. \tag{A.2}$$ {genantitwist}

The reason these conditions look so similar to those for chiral superfields is that there is no ideomatic difference between chiral and twisted-chiral superfields. To say more, they are interchanged by the action of mirror symmetry — the transposition of supercharges turns condition (A.1) into the one for a chiral superfield. This way, as in the case with the chiral superfields, the constraints (A.1) and (A.2) are solved by letting the superfields be arbitrary functions of "chiral" variables $\widetilde{y}^\mu$,

$$\begin{aligned} \Sigma &= \Sigma(\widetilde{y}^\mu) & \qquad \overline{\Sigma} &= \overline{\Sigma}(\overline{\widetilde{y}}^\mu) \\ \widetilde{y}^0 &= x^0 + i\left(\overline{\theta}_R\theta_R - \overline{\theta}_L\theta_L\right) & \qquad \overline{\widetilde{y}}^0 &= x^0 - i\left(\overline{\theta}_R\theta_R - \overline{\theta}_L\theta_L\right) \\ \widetilde{y}^3 &= x^3 + \left(\overline{\theta}_R\theta_R + \overline{\theta}_L\theta_L\right) & \qquad \overline{\widetilde{y}}^3 &= x^3 - \left(\overline{\theta}_R\theta_R + \overline{\theta}_L\theta_L\right)\,, \end{aligned}$$

after which they will have the usual "chiral" component expansion

$$\begin{aligned} \Sigma(\widetilde{y}) &= \sigma(\widetilde{y}) - \sqrt{2}\,\theta_R\overline{\lambda}_L + \sqrt{2}\,\overline{\theta}_L\lambda_R + \sqrt{2}\,\theta_R\overline{\theta}_L\,\widetilde{F} \\ \overline{\Sigma}(\overline{\widetilde{y}}) &= \overline{\sigma}(\overline{\widetilde{y}}) - \sqrt{2}\,\theta_L\overline{\lambda}_R + \sqrt{2}\,\overline{\theta}_R\lambda_L + \sqrt{2}\,\theta_L\overline{\theta}_R\,\overline{\widetilde{F}}\,. \end{aligned}$$

Here we understand that each function on the right hand side depends on $\widetilde{y}^\mu$ and $\overline{\widetilde{y}}^\mu$, correspondingly.

Exactly the same way as with chiral superfields, one constructs *twisted superpotentials* $\widetilde{\mathcal{W}}(\Sigma)$, just as functions that depend on Σ holomorphically. One then performs the twisted $d^2\tilde{\theta}$ integration as,

$$\int d^2\tilde{\theta}\,\widetilde{\mathcal{W}}(\Sigma) \;=\; \frac{1}{2}\,\overline{D}_L\,D_R\,\widetilde{\mathcal{W}}(\Sigma)\Big|\,, \qquad \int d^2\overline{\tilde{\theta}}\,\overline{\widetilde{\mathcal{W}}}(\overline{\Sigma}) \;=\; \frac{1}{2}\,\overline{D}_R\,D_L\,\overline{\widetilde{\mathcal{W}}}(\overline{\Sigma})\Big|\,. \tag{A.3}$$

And, of course, one can perform the full superspace integration of twisted superfields, provided that this holomorphicity is broken (*e.g.* by putting both chiral and anti-chiral factors),

$$\int d^4\theta \, \overline{\Sigma} \, \Sigma \,, \tag{A.4}$$

or the result will obviously be a total derivative.

One famous example of a twisted superfield is the *fieldstrength* of a $\mathcal{N} = (2,2)$ gauge supermultiplet V,

$$\Sigma \;=\; \frac{i}{\sqrt{2}} D_L \, \overline{D}_R \, V \,, \qquad\qquad \overline{\Sigma} \;=\; \frac{i}{\sqrt{2}} D_R \, \overline{D}_L \, V \,. \tag{A.5}$$

In components it takes the form

$$\begin{aligned} \Sigma(\widetilde{y}) \;&=\; \sigma(\widetilde{y}) \;-\; \sqrt{2}\,\theta_R \overline{\lambda}_L \;+\; \sqrt{2}\,\overline{\theta}_L \lambda_R \;+\; \sqrt{2}\,\theta_R \overline{\theta}_L \Big(D \;-\; i\,F_{03} \Big) \\ \overline{\Sigma}(\overline{\widetilde{y}}) \;&=\; \overline{\sigma}(\overline{\widetilde{y}}) \;-\; \sqrt{2}\,\theta_L \overline{\lambda}_R \;+\; \sqrt{2}\,\overline{\theta}_R \lambda_L \;+\; \sqrt{2}\,\theta_L \overline{\theta}_R \Big(D \;+\; i\,F_{03} \Big) \,. \end{aligned}$$

A.2 $\mathcal{N} = (0,2)$ superfields

We define $\mathcal{N} = (0,2)$ superspace via reduction of $\mathcal{N} = (2,2)$ superspace by putting

$$\theta_L \;=\; \overline{\theta}_L \;=\; 0 \,. \tag{A.6}$$

Each chiral and twisted-chiral $\mathcal{N} = (2,2)$ superfield this way splits into two $\mathcal{N} = (0,2)$ superfields. They still, however, retain their property of holomorphicity. While chiral superfields are usually described as being dependent on a "holomorphic" variable y^μ,

$$y^\mu \;=\; x^\mu \;+\; i\,\overline{\theta\sigma}_\mu \theta \,, \tag{A.7}$$

and twisted-chiral as dependent on a twisted variable $\widetilde{y}^\mu$,

$$\widetilde{y}^\mu \;=\; x^\mu \;+\; i\,\overline{\theta\widetilde{\sigma}}_\mu \theta \,, \tag{A.8}$$

the distinction between the two variables vanishes upon reduction to $\mathcal{N} = (0,2)$ superspace. As a result, $\mathcal{N} = (0,2)$ superspace defines only one kind of holomorphic superfields — chiral $\mathcal{N}=(0,2)$ superfields, which depend upon the reduced variables υ^μ

$$
\begin{aligned}
\upsilon^0 &= x^0 + i\,\overline{\theta}_R\theta_R \\
\upsilon^3 &= x^3 + i\,\overline{\theta}_R\theta_R\,. \qquad \text{(A.9)}
\end{aligned}
$$

To make a distinction with $\mathcal{N}=(2,2)$ superfields, we denote the $\mathcal{N}=(0,2)$ superfields by symbols with a hat on top — $\hat{\sigma}$, $\hat{\xi}$, *etc.*

Chiral superfields $\Phi(y)$ split into $\mathcal{N}=(0,2)$ superfields $\hat{\phi}(\upsilon)$ and $\hat{\xi}(\upsilon)$,

$$
\begin{aligned}
\Phi(y) &\longrightarrow \hat{\phi}(\upsilon) + \sqrt{2}\,\theta_L\,\hat{\xi}(\upsilon)\,, \\
\overline{\Phi}(\overline{y}) &\longrightarrow \hat{\overline{\phi}}(\overline{\upsilon}) - \sqrt{2}\,\overline{\theta}_L\,\hat{\overline{\xi}}(\overline{\upsilon})\,, \qquad \text{(A.10)}
\end{aligned}
$$ {Phisplit}

while twisted-chiral superfields $\Sigma(\widetilde{y})$ split into $\hat{\sigma}(\upsilon)$ and $\hat{\lambda}(\upsilon)$,

$$
\begin{aligned}
\Sigma(\widetilde{y}) &\longrightarrow \hat{\sigma}(\upsilon) + \sqrt{2}\,\overline{\theta}_L\,\hat{\lambda}(\upsilon)\,, \\
\overline{\Sigma}(\overline{\widetilde{y}}) &\longrightarrow \hat{\overline{\sigma}}(\overline{\upsilon}) - \sqrt{2}\,\theta_L\,\hat{\overline{\lambda}}(\upsilon)\,. \qquad \text{(A.11)}
\end{aligned}
$$ {Sigmasplit}

We alert that relations (A.10) and (A.11) have only symbolical meaning demonstrating the effect of splitting, while there is no equality: the right-hand sides have incomplete dependence on θ_L, $\overline{\theta}_L$.

The individual $\mathcal{N}=(0,2)$ superfields have a quite straightforward component expansion,

$$
\begin{aligned}
\hat{\phi}(\upsilon) &= \phi - \sqrt{2}\,\theta_R\,\psi_L\,, & \hat{\xi}(\upsilon) &= \psi_R + \sqrt{2}\,\theta_R\,F\,, \\
\hat{\overline{\phi}}(\overline{\upsilon}) &= \overline{\phi} + \sqrt{2}\,\overline{\theta_L\psi}_L\,, & \hat{\overline{\xi}}(\overline{\upsilon}) &= \overline{\psi}_R + \sqrt{2}\,\overline{\theta_R F}\,, \qquad \text{(A.12)}
\end{aligned}
$$

and similarly do the ones that arise from splitting of the the twisted chiral superfield $\Sigma(\widetilde{y})$,

$$
\begin{aligned}
\hat{\sigma}(\upsilon) &= \sigma - \sqrt{2}\,\theta_R\,\overline{\lambda}_L\,, & \hat{\lambda}(\upsilon) &= \lambda_R - \theta_R\,\widetilde{F}\,, \\
\hat{\overline{\sigma}}(\overline{\upsilon}) &= \overline{\sigma} + \sqrt{2}\,\overline{\theta}_R\,\lambda_L\,, & \hat{\overline{\lambda}}(\overline{\upsilon}) &= \overline{\lambda}_R - \overline{\theta}_R\,\overline{\widetilde{F}}\,. \qquad \text{(A.13)}
\end{aligned}
$$

It is interesting to note that the simple structure of splitting shown in (A.10) and (A.11) makes fermionic superfields in $\mathcal{N}=(0,2)$ superspace much more ubiquitous than in $\mathcal{N} = (2,2)$ superspace. And the first example to this is the $\mathcal{N} = (0,2)$ superpotential. It has to be fermionic because the integration over *half* of the $\mathcal{N} = (0,2)$ superspace $d\theta_R$ is such. A superpotential can be constructed using an arbitrary holomorphic function — say $J(\hat{\sigma})$, and by multiplying it by an arbitrary (but still chiral) fermionic multiplet — say $\hat{\rho}$,

$$\int d\theta_R \, \hat{\rho} \, J(\hat{\sigma}) \, . \tag{A.14}$$

"Full" superspace integrals can conventionally be built using both chiral and antichiral fields,

$$\int d^2\theta_R \; \hat{\xi}\,\hat{\overline{\xi}} \quad = \quad \overline{\psi}_R \, i\partial_L \psi_R \quad + \quad \overline{F}\, F \, . \tag{A.15}$$

B Component Expansion of the Effective Action

{app:expansion

Here we give the complete component expansion of expression (??). Typically, one would be interested in a specific limit of this expression, such as the bosonic part of it, or the constant bosonic part, or an approximation in the certain number of space-time derivatives (some approximations, however, are easier to derive from the series representation (??)).

We make a remark that, according to [2], the whole fermionic part of the below effective Lagrangian can be obtained from its bosonic part simply via a replacement

$$\sqrt{2}\sigma \quad \longrightarrow \quad \sqrt{2}\sigma \quad + \quad 2\,\frac{i\,\overline{\lambda}_L \lambda_R}{iD + F_{03}} \, . \tag{B.16}$$

It is useful to know the lowest component of the superfield S,

$$s \quad = \quad S\Big| \quad = \quad \frac{\sqrt{2}\overline{\sigma}\,(iD \;-\; F_{03}) \;-\; 2\,i\,\overline{\lambda}_R\lambda_L}{\left(\sqrt{2}\,\overline{\sigma}\right)^2} \, ,$$

$$\overline{s} \quad = \quad \overline{S}\Big| \quad = \quad \frac{\sqrt{2}\sigma\,(iD \;+\; F_{03}) \;-\; 2\,i\,\overline{\lambda}_L\lambda_R}{\left(\sqrt{2}\,\sigma\right)^2} \, .$$

In the expression below, however, we extensively make use of the lowest component of the ratio $S/(\sqrt{2}\Sigma)$, which we denote as p,

$$
\begin{aligned}
p \;&=\; \left.\frac{S}{\sqrt{2}\Sigma}\right| \;=\; \frac{1}{\left|\sqrt{2}\sigma\right|^2}\left(iD \,-\, F_{03} \;-\; \frac{2\,i\sqrt{2}\sigma\overline{\lambda}_R\lambda_L}{\left|\sqrt{2}\sigma\right|^2}\right)\,, \\
\overline{p} \;&=\; \left.\frac{\overline{S}}{\sqrt{2}\overline{\Sigma}}\right| \;=\; \frac{1}{\left|\sqrt{2}\sigma\right|^2}\left(iD \,+\, F_{03} \;-\; \frac{2\,i\sqrt{2}\overline{\sigma}\overline{\lambda}_L\lambda_R}{\left|\sqrt{2}\sigma\right|^2}\right)\,.
\end{aligned}
$$

We have,

$$
\begin{aligned}
\frac{4\pi}{N}\mathcal{L} \;&=\; iD \;-\; F_{03}\,\log\frac{\sqrt{2}\sigma}{\sqrt{2}\overline{\sigma}} \;-\; i\,\frac{\sqrt{2}\sigma\overline{\lambda}_R\lambda_L \;+\; \sqrt{2}\overline{\sigma}\overline{\lambda}_L\lambda_R}{\left|\sqrt{2}\sigma\right|^2} \;- \\
&-\; \frac{1}{4}\,\ln\sqrt{2}\sigma\,\Box\,\ln\sqrt{2}\sigma \;-\; \frac{1}{4}\,\ln\sqrt{2}\overline{\sigma}\,\Box\,\ln\sqrt{2}\overline{\sigma} \;- \\
&-\; \frac{1}{2}\left(iD \,+\, F_{03} \,+\, \frac{1}{2}\,\Box\,\ln\sqrt{2}\overline{\sigma}\right)\,\ln\left(\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,-\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}\right) \;- \\
&-\; \frac{1}{2}\left(iD \,-\, F_{03} \,+\, \frac{1}{2}\,\Box\,\ln\sqrt{2}\sigma\right)\,\ln\left(\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,+\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}\right) \\
&+\; \frac{-\,\overline{\lambda}_R\,i\overleftarrow{\mathcal{D}}_L\lambda_R \;+\; \overline{\lambda}_L\,i\mathcal{D}_R\lambda_L \;-\; \frac{1}{2}\,i\,\sqrt{2}\overline{\sigma}\overline{\lambda}_L\lambda_R \;+\; \frac{1}{2}\,\frac{1}{\sqrt{2}\overline{\sigma}}\,i\,\overline{\lambda}_R\overleftarrow{\mathcal{D}}_L\,\mathcal{D}_R\lambda_L}{\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,-\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}} \\
&+\; \frac{\overline{\lambda}_R\,i\mathcal{D}_L\lambda_R \;-\; \overline{\lambda}_L\,i\overleftarrow{\mathcal{D}}_R\lambda_L \;-\; \frac{1}{2}\,i\,\sqrt{2}\sigma\overline{\lambda}_R\lambda_L \;+\; \frac{1}{2}\,\frac{1}{\sqrt{2}\sigma}\,i\,\overline{\lambda}_L\overleftarrow{\mathcal{D}}_R\,\mathcal{D}_L\lambda_R}{\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,+\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}} \\
&-\; \frac{1}{4}\,\frac{\left|\sqrt{2}\sigma\right|^2\,\left(iD \,+\, F_{03} \,+\, \Box\,\ln\sqrt{2}\overline{\sigma}\right)}{\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,-\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}} \;-\; \frac{1}{4}\,\frac{\left|\sqrt{2}\sigma\right|^2\,\left(iD \,-\, F_{03} \,+\, \Box\,\ln\sqrt{2}\sigma\right)}{\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,+\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}} \\
&-\; \frac{1}{2}\left|\sqrt{2}\sigma\right|^2\,\left(1 \,+\, \frac{1}{p}\right)\,\frac{-\,\overline{\lambda}_R\,i\overleftarrow{\mathcal{D}}_L\lambda_R \,+\, \overline{\lambda}_L\,i\mathcal{D}_R\lambda_L \,+\, i\,\sqrt{2}\overline{\sigma}\overline{\lambda}_L\lambda_R \,+\, \frac{1}{\sqrt{2}\overline{\sigma}}\,i\,\overline{\lambda}_R\overleftarrow{\mathcal{D}}_L\,\mathcal{D}_R\lambda_L}{\left(\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,-\, F_{03} \,-\, 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}\right)^2}
\end{aligned}
$$

$$
\begin{aligned}
&- \frac{1}{2}\left|\sqrt{2}\sigma\right|^2 \left(1 + \frac{1}{p}\right) \frac{\overline{\lambda}_R\, i\mathcal{D}_L\lambda_R - \overline{\lambda}_L\, i\overleftarrow{\mathcal{D}}_R\lambda_L + i\sqrt{2}\sigma\overline{\lambda}_R\lambda_L + \frac{1}{\sqrt{2}\sigma}\, i\,\overline{\lambda}_L\overleftarrow{\mathcal{D}}_R\,\mathcal{D}_L\lambda_R}{\left(\left|\sqrt{2}\sigma\right|^2 + iD + F_{03} - 2i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}\right)^2} \\
&+ \frac{1}{2\,p^3}\Bigg(-p^2\left(iD + F_{03}\right) + \frac{1}{2}\,p\,\Box\ln\sqrt{2}\overline{\sigma} - 2\,p^2\, i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma} + \qquad\qquad \text{(B.17)} \\
&\qquad + 2\,i\,\frac{1}{\sqrt{2}\sigma}\,\frac{\overline{\lambda}_R\overleftarrow{\mathcal{D}}_L\,\mathcal{D}_R\lambda_L}{\left(\sqrt{2}\overline{\sigma}\right)^2} - 2\,p\,\frac{\overline{\lambda}_L\, i\mathcal{D}_R\lambda_L - \overline{\lambda}_R\, i\overleftarrow{\mathcal{D}}_L\lambda_R}{\left|\sqrt{2}\sigma\right|^2}\Bigg)\cdot\ln\left(1 + p\right) \\
&+ \frac{1}{2\,\overline{p}^3}\Bigg(-\overline{p}^2\left(iD - F_{03}\right) + \frac{1}{2}\,\overline{p}\,\Box\ln\sqrt{2}\sigma - 2\,\overline{p}^2\, i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}} + \\
&\qquad + 2\,i\,\frac{1}{\sqrt{2}\overline{\sigma}}\,\frac{\overline{\lambda}_L\overleftarrow{\mathcal{D}}_R\,\mathcal{D}_L\lambda_L}{\left(\sqrt{2}\sigma\right)^2} - 2\,\overline{p}\,\frac{\overline{\lambda}_R\, i\mathcal{D}_L\lambda_R - \overline{\lambda}_L\, i\overleftarrow{\mathcal{D}}_R\lambda_L}{\left|\sqrt{2}\sigma\right|^2}\Bigg)\cdot\ln\left(1 + \overline{p}\right) \\
&+ \frac{1}{2\,p^2}\, i\left(\frac{-\sqrt{2\sigma}\overline{\lambda}_L - \overline{\lambda}_R\overleftarrow{\mathcal{D}}_L}{\left|\sqrt{2}\sigma\right|^2 + iD - F_{03} - 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}} + \frac{\overline{\lambda}_L}{\sqrt{2}\sigma}\right)\left(2\,p\,\lambda_R + \frac{\mathcal{D}_R\lambda_L}{\sqrt{2}\overline{\sigma}}\right) \\
&+ \frac{1}{2\,\overline{p}^2}\, i\left(\frac{-\sqrt{2}\sigma\overline{\lambda}_R - \overline{\lambda}_L\overleftarrow{\mathcal{D}}_R}{\left|\sqrt{2}\sigma\right|^2 + iD + F_{03} - 2i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}} + \frac{\overline{\lambda}_R}{\sqrt{2}\overline{\sigma}}\right)\left(2\,\overline{p}\,\lambda_L + \frac{\mathcal{D}_L\lambda_R}{\sqrt{2}\sigma}\right) \\
&+ \frac{1}{2\,p^2}\, i\left(-2\,p\,\overline{\lambda}_L + \frac{\overline{\lambda}_R\overleftarrow{\mathcal{D}}_L}{\sqrt{2}\overline{\sigma}}\right)\left(\frac{\sqrt{2}\overline{\sigma}\lambda_R - \mathcal{D}_R\lambda_L}{\left|\sqrt{2}\sigma\right|^2 + iD - F_{03} - 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}} - \frac{\lambda_R}{\sqrt{2}\sigma}\right) \\
&+ \frac{1}{2\,\overline{p}^2}\, i\left(-2\,\overline{p}\,\overline{\lambda}_R + \frac{\overline{\lambda}_L\overleftarrow{\mathcal{D}}_R}{\sqrt{2}\sigma}\right)\left(\frac{\sqrt{2}\sigma\lambda_L - \mathcal{D}_L\lambda_R}{\left|\sqrt{2}\sigma\right|^2 + iD + F_{03} - 2i\,\frac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}} - \frac{\lambda_L}{\sqrt{2}\overline{\sigma}}\right) \\
&- \frac{1}{4\,p}\left|\sqrt{2}\sigma\right|^2 \frac{iD + F_{03} + \Box\ln\sqrt{2}\overline{\sigma}}{\left|\sqrt{2}\sigma\right|^2 + iD - F_{03} - 2i\,\frac{\overline{\lambda}_R\lambda_L}{\sqrt{2}\overline{\sigma}}} + \frac{1}{4}\left|\sqrt{2}\sigma\right|^2\frac{\overline{p}}{p}
\end{aligned}
$$

$$- \quad \frac{1}{4\,\overline{p}}\left|\sqrt{2}\sigma\right|^2 \frac{iD \,-\, F_{03} \,+\, \Box \ln\sqrt{2}\sigma}{\left|\sqrt{2}\sigma\right|^2 \,+\, iD \,+\, F_{03} \,-\, 2i\,\dfrac{\overline{\lambda}_L\lambda_R}{\sqrt{2}\sigma}} \quad + \quad \frac{1}{4}\left|\sqrt{2}\sigma\right|^2 \frac{p}{\overline{p}}\,.$$

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